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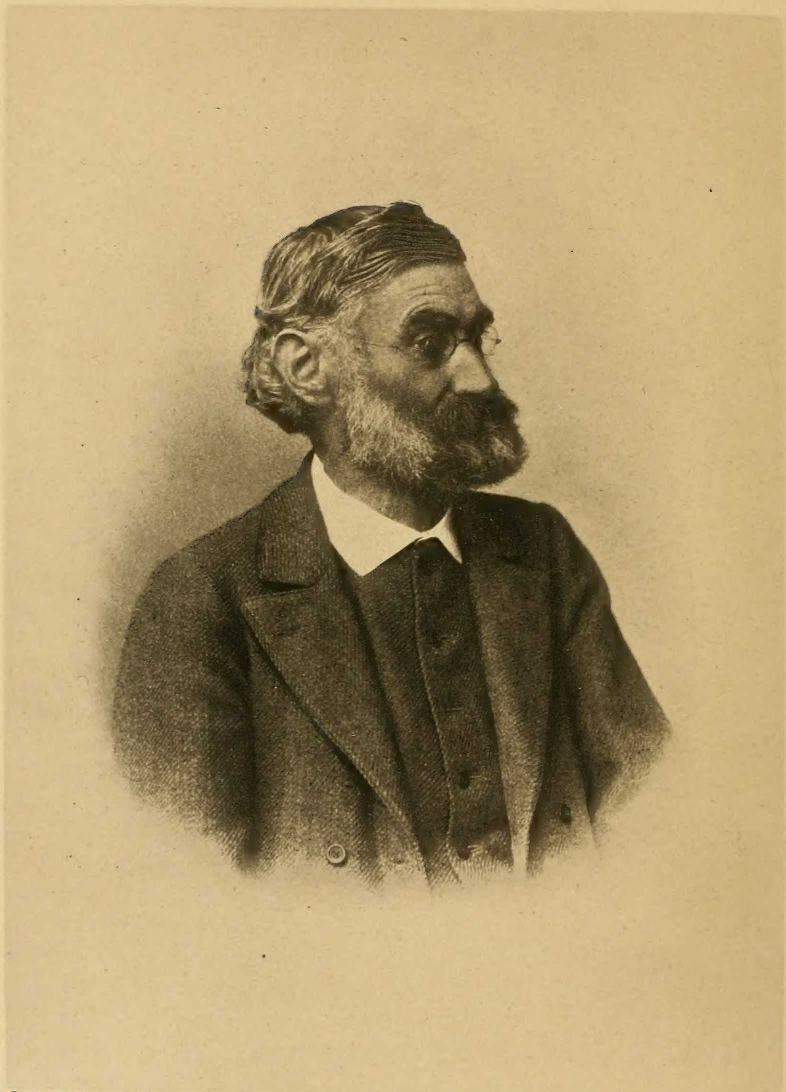

Phot. von Bräunlich & Tesch, Jena

Dr. E. Abbe

THE ZEISS WORKS

AND

THE CARL ZEISS FOUNDATION IN JENA

THEIR SCIENTIFIC, TECHNICAL AND SOCIOLOGICAL DEVELOPMENT AND IMPORTANCE POPULARLY DESCRIBED

BY

PROF. FELIX AUERBACH

TRANSLATED FROM THE FIFTH GERMAN EDITION BY
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WITH A FOREWORD BY
PROF. CHESHIRE C.B.E.

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FOREWORD.

I gladly accede to the request of my Jena friends that I should write a short foreword for this new edition of Auerbach's "Carl Zeiss Foundation". It is now more than 20 years since the first edition appeared, and 30 years have elapsed since the creation of the Foundation itself. Abbe's scheme may, therefore, be now accepted as having passed through the experimental stage, and as having achieved a remarkable and unique success, the keynote to which can be put in a few words—the scientific organisation and direction of labour—the truth which is being driven home so persistently and ruthlessly throughout the world to-day.

To those interested in the manufacture and development of optical instruments and their uses as tools, the book appeals directly, but the evidence which it gives of the working out in detail of Abbe's scheme for the solution of the eternal problem of capital and labour should and probably will interest a much larger circle of readers.

Science to-day owes a great debt to the Carl Zeiss Foundation.

FREDERIC J. CHESHIRE

(Late Director of the Optical Engineering Dept. of the Imperial College of Science and Technology, London)

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Introduction.

It has been said that the fascination of a story grows with the spirit of unity which runs through the wealth of its details and with the vividness with which it proceeds from the special and commonplace to the general and extraordinary. If this be so, the contents of these pages should not fail entirely to arouse the interest of a good many readers. For our story relates to one out of many thousands of large industrial activities which supply our modern humanity with its wants. Our story will endeavour to view this one industry from all sides, and it will have much to relate about its historical progress and social influences no less than its scientific and technical development. But through all the scenes and events of our story there runs a single thread. It is the tale of a journey towards a common goal. All is dominated by a unifying ideal, which is to surround labour, man's most precious gift according to the Bible and his inner consciousness, with conditions which may truly make it so, to so shape the aspect of work that it may be the reward of his life and not its penalty.

The ideas and aims which will make up the burden of our story are by no means new, neither in their scientific and technical nor in their social and moral aspects. In many heads, no doubt, they have slumbered for years in fitful restlessness, and ever and anon they may have reached the stage of a half-dreaming awakening. But, in company with many practical successes, the endeavours to translate these ideals into action again and again resulted in failure, so much so that often enough doubt entered the abode of confident faith. We seem to be listening to the obvious when we hear it said that "industry should be firmly founded on science" or that "the interest of the employer should be regarded as identical with that of the worker". Many of these seeming axioms have been enunciated in various keys, and widely as they differ in their spirit, they all have this in common that it is easy, though apparently only, to crush them by *argumenta ad absurdum,* while it is difficult to prove that none the less they contain the truth. It is the inevitable fate of these fundamental ideas that, unless pursued with unerring clearness and unconquerable energy and tenacity, in

defiance of all opposing difficulties, they refuse to be translated into a positive achievement. The results have almost invaribly proved to be negative. All that results is a vaguely felt realisation that man is capable of beautiful and noble ideas, but that, human nature being what it is, their embodiment in practical achievements is doomed to failure. It is the old, old story of free ideas dwelling side by side with the rudely colliding realities of life: — "We build statues of snow and weep to see them melt".

In the school of hard experience convictions had arisen which were only partly true, but it needed a mighty effort to overcome convictions founded on half a truth. An unshakable faith and an iron will was needed to prove that the old belief was true so long only as man's thoughts failed to take heed of the facts or even persisted in assailing them. It needed a hard fight to show that that belief breaks down so soon as the ideas enter into an alliance with the facts in loving comprehension of their true nature. In other words, what was needed was a fundamental conviction in a spirit of optimism. It needed the firm realisation that where thoughts are good and clear it should be possible to conclude that there is a corresponding reality behind them. On such a foundation only was it possible to erect an edifice whose pillars and beams, whose design and construction, warming and ventilation should be the outcome of pure abstract thought, a triumph, indeed, of 'grey' theory. It is a story full of hope and encouragement, this story of ours; for it tells us that this edifice, despite many and loud prophesies, has neither subsided nor crumbled into the dust, but now stands firmly on its foundations, fit to bear the weight of added heights and full of the promise of further extension.

The subject of these reflections is the Carl Zeiss Foundation at Jena, which embraces within its scheme industrial establishments devoted to the manufacture of optical material and optical instruments. When it is realised that these establishments employ at present some seven thousand persons, including a staff of over fifty scientific specialists and about three hundred engineers, technical assistants, foremen and so forth, it follows that among all the manufacturing concerns of this kind this great establishment occupies an entirely unique position. It owes this to two cirmcustances which are ordinarily held to be incompatible. These two seemingly antagonistic elements are the very high *excellence* of the products and their great range of *diversity*. That these two elements do in a sense present irreconcilable aspects in manufacture will not be difficult to see.

Obviously a product cannot be expected to be excellent unless it is the outcome of advanced theoretical understanding and great technical resources, and this again implies that the manufacturer, or rather every person engaged in the manufacture, bestows his undivided experience, intelligence, and time upon a particular object of manufacture. The strength of modern production lies in organised division of labour. In a modern factory this system of specialisation sees to it that every worker operates within a narrowly circumscribed boundary, and it follows that within these limits he becomes in time an expert with whom others cannot compete.

Now, if we apply this principle to an industrial undertaking as a whole, it would seem to follow that a successful concern should confine itself to the manufacture of a certain article, such as microscopes, and during the first forty years of the existence of the Zeiss Works this principle has, as a matter of fact, been rigidly adhered to. Here again we find the principle of complete division of labour at work, in that the manufacture of all other objects is left to other establishments, whilst all available resources are concentrated in one direction, the manufacture of microscopes, and incidentally with the aim of producing the best that the world can furnish. But timely wisdom showed that, as every practical principle has its limits, there must arise a point beyond which its application in the manufacture of one particular class of instruments in limited demand might do harm rather than prove effective. That the works at Jena have expanded to their present magnitude is the merit of Prof. Abbe and his successors, in that they were able at the right moment to determine that the principle of the division of labour had reached its limits.

As the result of this freer policy one new object after another was included in the scope of manufacture, and no year passes but that one or the other special items is added to the factory's catalogue. It is by reason of this very vastness of its range of interests coupled with an invulnerable standard of highest excellence that the great establishment at Jena presents a singularly interesting phenomenon. The establishment is not without its rivals in quality, and indeed it acknowledges its compeers in one or the other branch of achievement, but viewed as a whole it knows no equal.

Three optical periods.

The history of practical optics, upon which we must now bestow a glance, in order to appreciate the significance of the undertaking at Jena, may in a certain sense be divided into three periods. The first may be described as scientific, the second as unscientific, and the third again as scientific. The evolution of practical optics has accordingly described a kind of wave-line beginning with a crest, dipping into a vale, and rising again to a crest. In oldest times when simple instruments were made with the simplest means, practical optics moved upon a plane of elementary science in that its function consisted in applying in a tangible form the simplest laws of light, its reflection and refraction. It is along these lines that the Moors became famed in optics, and their example was emulated by the first Western opticians after the awakening of mediaeval torpor to modern life. Within the limits of their age the opticians of that early period were therefore up to date, as it were. They were perched upon an optical crest, though, maybe, only the crest of a flat hillock. Then came a time when aims rose and, with steadily growing visions and wants, with which the intellectual resources failed to keep pace, achievement became more and more problematic. Craftsmen then forsook the path of science and fumbled about in the dark, pinning their faith on the rule of thumb. Now, we know that in a game of chance there are always a few lucky, and often big, prizes to be won, and so it happened that even during this period of purely empirical optics much practical progress was made, but it cannot be wondered at that the number and significance of the achievements of this period, are out of all proportion to the expenditure of time and effort of the optical craftsmen. And when all is said and done, these achievements can only be looked upon as side issues. The desired goal could not be reached in this way.

This final achievement remained reserved for the third period, the age of modern scientific research.

This is not the place to pay tribute to the great pioneers, such as Fraunhofer and Herschel for their achievements in telescopic optics, Petzval and Steinheil in photographic optics, and so forth. — The purpose of our story is to pass in review the influence of what has been done at Jena and to learn from the story of CARL ZEISS, ERNST ABBE and OTTO SCHOTT, how by the bold conceptions of these three men and their marked influence upon the systematic development of modern optics the Jena Works have come to be what they are now.

The New Era of the Microscope.

In 1846 CARL ZEISS[1] established himself as a scientific instrument maker in a small workshop in Jena, the well-known Thuringian university town. There is nothing remarkable about this fact in itself since the existence of workshops such as Zeiss established at Jena are regarded as a necessity to any university which has attached to it laboratories for practical teaching

Fig. 1. First workshop (Neugasse)

Fig. 2. Second workshop (Wagnergasse)

and research in the natural sciences and medicine, and in general the owner of such a workshop would be content to keep himself going by making instruments and executing repairs for his local patrons. But Zeiss, though unquestionably an unpretentious man, did not belong to the category of facilely contented natures. He was one of those who strive, and must strive, to achieve something better and higher than what is just sufficient. There would be a void in the lives of such men without this incentive.

There is a very natural affinity between the instrument maker's craft and practical optics, and the time when Zeiss began operations and the

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[1] Carl Zeiss, born on the 11th September 1816 at Weimar, was the son of the proprietor of a toy business and incidentally instructed the grand-duke Charles Frederick in the art of turning. He attended the "Gymnasium" (school of classical education) up to the standard known in Germany as "Prima" (standard comparable to the matriculation requirements of our greater universities). He then served his apprenticeship and further improved himself in instrument makers' and machine shops in Weimar (Koerner), Stuttgart and Vienna, and in 1846 established the firm of Carl Zeiss at Jena, which subsequently grew into a gigantic concern. In 1881 the University of Jena recognised his (indirect) services to science by conferring upon him the honorary degree of a doctor of philosophy. He died on the 3rd December 1888.

spirit of research at Jena were alike favourable to infuse new life into optical progress. It may suffice to recall the fact that at this very time JAKOB SCHLEIDEN, the masterly exponent of the then budding cellular theory, was hard at work. It will be readily understood that for the solution of the problems which the leaders of the new school of morphological research envisioned the then available tools of microscopic seeing were wholly inadequate. It was mainly Schleiden who directed the young mechanician, always ready to acquire fresh knowledge, into the field of optics. It was he, too, who watched his progress with the warmest interest and made it his business to bring Zeiss's name to the notice of a wide circle of friends and colleagues [1].

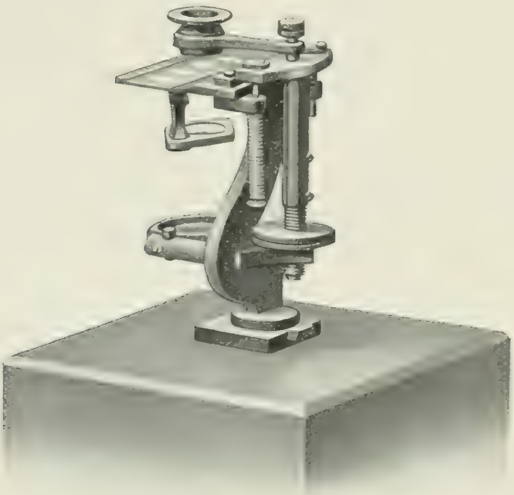

Fig. 3. Simple Microscope of 1848.

In the earlier stages everything went remarkably well. Zeiss confined himself mainly to the manufacture of so-called "simple" microscopes (with doublet and triplet magnifiers). One of these types, designed in 1848 and historically interesting, for which reason we show it in fig. 3, met with so much approval that two thousand of these little instruments were disposed of during its life. In due course Zeiss proceeded to make microscopes, as generally understood, that is to say, so-called "compound" microscopes equipped with objectives and eyepieces or oculars. At first his productions were no better and no worse than those which then emanated from other optical workshops of established reputation. When, however, Zeiss began to set himself a

[1] In 1857 already Schleiden wrote Zeiss at his request a testimonial, which contains the following statement: "Herr Zeiss has asked me to recommend his work, and I must confess, I do not quite know why. My recommendation can only be of value as regards his optical work, and this, surely, stands in no need of a word from me. Herr Zeiss describes his microscopes as no more than first attempts, and this modesty does him as much credit as his skill and art. As regards the optical portion these first attempts may well range themselves at the side of the work of old masters, and they justify the expectation that Herr Zeiss will not fail to reach the standard of the best existing microscopes and that he will probably surpass them", etc.

higher goal he realised the inadequacy of his resources and he soon found himself at the crossways. Was he to steer into the safe harbour of standard mediocrity, or was he to devise means by which he might be able to brave

Fig. 4. Carl Zeiss.

the rising storm of modern requirements? He chose the latter course. He ventured upon the high seas, which proved that he had courage. He would not do so alone, but sought the guidance of a pilot, which proved his

wisdom, and since he had "the wisdom that did guide his valour", ultimate success could not fail him.

Like every figure of speech, the simile of the pilot must not be taken too literally. A pilot, it must be remembered, is a guide adopted where the captain's knowledge is at fault. He is one who knows, and indeed very accurately knows, the region which is to be traversed. In Zeiss's case it was not, however, a matter of travelling over a known region but rather of treading almost wholly undiscovered paths. The problem was to find a course that should lead to the construction of a scientifically evolved microscope. To tackle this problem no expert existed in those days. It was not therefore a question of finding the expert but rather the explorer who had the spirit and the genius to become the idealised expert. The man who was endowed with these qualities needed a third great quality. He must have a volume of insight which enabled him to face with equanimity much initial failure, and he must be prepared at best to reach his destination only after patiently laborious efforts and the defeat of undreamt difficulties. Where such mental resources and moral qualities were needed it should not surprise us that the first "pilot" with whom Zeiss essayed his first voyage into unknown seas found himself helpless on the rocks before the voyage had well begun. Such being the first rebuff, it was something more than mere good fortune which let his second choice lead him to the right man. This was ERNST ABBE[1], and it was only after long laborious efforts, in which both men joined hands, that their envisioned goal was ultimately reached.

We will now return to the subject of microscopes. To appreciate the work attempted by Zeiss and Abbe it must be realised that even the best microscopes made at that time, — apart from the practical embodiment of the elementary laws of light, which were naturally the pure contributions of science, — were not scientific achievements but the results of hundred-fold trials. The lenses required for the eyepieces and objectives were ground and polished and the resulting images of small objects carefully viewed

[1] Ernst Abbe, born on the 23rd January 1840, was the son of a foreman spinner in the mill of Eichel in Eisenach. He subsequently studied in Jena and Goettingen. His examiners in Goettingen were Riemann and Wilhelm Weber, and by his thesis on the mechanical equivalent of heat he graduated as a doctor in philosophy. For a short time he was domiciled in Frankfort o. M. as a tutor (Dozent), and in 1863 he attached himself to the university of Jena by a thesis on the calculation of errors arising in the subjects of mathematics, physics and astronomy. In 1866 began his connection with Carl Zeiss and in 1870 he was appointed an extraordinary professor at the university. When in 1874 it was decided to found a physical institute in Jena he was offered the professorship of physics, but he declined the honour in view of the circumstances and his desire to devote himself exclusively to the needs of the optical establishment, whose

and criticised. In this way the succeeding years furnished an increasing store of information as to the form of lenses which were required to attain a certain result; or rather, to express ourselves more correctly in a negative sense, how the lenses should be formed and combined in order to eliminate certain defects, such as unsharp images, a difference in the central and marginal magnification, coloured fringes, insufficient light, etc. When the data of a lens were slightly altered, in order to eliminate a certain defect in the image, it was frequently found, as might be readily expected, that, whilst the original intention was attained, the other defects possibly became accentuated. Changes were introduced again and again, and since a faultless optical image is required to possess a multitude of good qualities, there would be such an immense number of conditions to fulfil that probably centuries would not have sufficed in order to ultimately arrive at the discovery of the ideal microscope, and even then it would need the oft repeated help of an extraordinary stroke of luck.

To put a radical end to such a deplorable state of things there was only one way, and that was not to rest content to pursue and apply the fundamental laws of optics but to unravel with the same scientific precision *all* the details affecting the course of the rays. To achieve complete independence from the results of the old trial and error system it would be necessary to establish unambiguous formulae from which it could be seen with mathematical precision what diameters, thicknesses, curvatures, and mutual distances the lenses would have to be given in order that the resulting combination may be free from defects, or rather in order that these defects may be reduced to a minimum, since it was not reasonably to be expected that all defects could possibly be eliminated in their entirety. In this way only was it feasibly possible to create an instrument, — at all events in the abstract to begin with, — which, when carried out with technical precision, might not prove a failure calling for a renewed effort.

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cause he had espoused. The University of Halle conferred on Abbe the honorary degree of a doctor of medicine, and he was also an honorary doctor of law of the University of Jena and a member of numerous learned societies. In 1871 he married under the most modest economic conditions a daughter of his former teacher, Prof. Snell of Jena. Mrs. Abbe died in 1914, and there are two daughters living. The baneful effects of overwork and strife against opposition, enormous responsibilities and fateful decisions induced serious nervous troubles, and this condition, together with the evil effects produced by the remedies used, undermined Abbe's health so completely that at the beginning of the new century he was compelled to withdraw from his professional duties. But the comparative leisure so obtained did not bring about any lasting improvement, and soon all hope vanished that the remaining years of quiet might serve to collect and record all that had been stored in the recesses of an all but too rich intellect. Abbe died on the 14th January 1905.

Naturally, such a scientifically exact system demanded for its successful application fresh improvements in mechanical technique. For now it became necessary to realise by practical achievement precisely stated data in a similarly precise manner, — precise in the sense of a steadily increasing approximation to an ideal of perfection, — so that deviations from the required thickness of a lens or its radius of curvature might not exceed $^1/_{20}$ of its lowest value, until gradually the tolerance was not allowed to amount to more than $^1/_{50}$, $^1/_{100}$ and finally less and less. To ensure such a degree of precision very exacting tests and standard gauges had to be devised and put into requisition. One of these incomparably delicate tests is one which consists in the application of Newton's colour rings due to the mutual interference of light waves. This enables the lens maker to control the most important element in lens construction, the constant sphericity of the curvature of a lens surface. For these colour rings appear when two surfaces placed in contact differ very slightly in their curvatures, and hence a lens surface in the making is not identical with the oppositely curved standard lens surface, and accordingly accepted as complete and perfect, unless these Newtonian colours disappear. This important test had been thought out by Fraunhofer many years earlier in connection with the making of telescope lenses, but it was introduced into the optical works of Carl Zeiss as an independently developed idea by the first foreman optician of the establishment. This was AUGUST LÖBER, a man of great resources, who had a peculiar gift for grappling with subtle technical problems, and there is no doubt that as the direct and indirect instructor of all Jena opticians he contributed his full share of influence in the rise of the undertaking. The other elements which enter into the construction of more or less complex lens combinations, such as the thicknesses of the lenses, the flatness of their plane surfaces, the diameter of the lenses, the distances separating the component lenses of a combination, their centration and so on, were rendered subject to increasingly refined methods of control, and incidentally this gave rise to the invention and construction of special instruments.

But we have been anticipating. We are as yet only concerned with the scientific predetermination of all the factors which go to produce a certain required optical effect. We have already seen that the mere problem of calculation was sufficiently involved to admit only of a very gradual approach to mathematical perfection. It was inevitably necessary to begin with simple formulae satisfying the primary conditions and to gradually introduce further refinements with the growth of experience and resources. There was, however, one fundamental idea which from the first stood firm

as an inflexible principle. The system embarked upon banned throughout the process of manufacture anything in the nature of trial, modification, or variation. The lens grinder was rigorously tied to the data furnished by the mathematical formula. Let the result be good, bad, or indifferent, his duty it was to produce the exact embodiment of the achievement of theoretical calculation.

In the hands of an impatient pioneer this principle was not free from great dangers. It might easily happen that the first products of this scientific method of constructive optics, as obtained within the limits of first approximation, turned out to be inferior to the best achievements of optical art which relied on the results of trial and the accumulated experiences of several decades. Jena did not lack these experiences, but did not wish to know them any longer. Our pioneers were fully prepared for these failures and they remained undaunted. They did not expect to score a victory at a first attack, but they remained equally confident that in time design and knowledge must beat a game of chance.

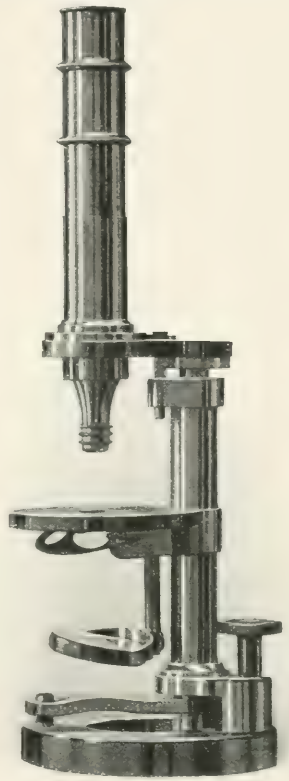

Fig. 5.
Old Microscope of 1859.

And now, to worthily appreciate the full merit which falls to the share of Carl Zeiss in this bold undertaking we must picture to ourselves a simple and plain man of the people, who sees and comprehends the things all around him as through a thin veil or mist. We must imagine him hearing during the day much of formulae, drawings, and figures serving new plans and in the evening pouring over books in a grim endeavour to familiarise himself with these things within the limits of his powers. We must think of him as of a man whose business was progressing tolerably well and would in all probability have moved successfully along the old track. And yet this man, with all the limitations of circumstance against him, entered upon a venture so hazardous in his days that wise men shook their heads in view of such futility. For it must be remembered that science has at no time stood overhigh in the affections of practice, and it is especially

when technical problems assume a rather complex aspect that theory is always sure to meet with cold distrust. Indeed, many years later a notable and well informed authority on microscopy, who stood in close personal relation to one of the best opticians of the old school and therefore was thoroughly acquainted with the practical side of optical construction, gave it as his opinion that microscopes could not possibly be produced on the foundations of theory owing to their complicated nature. So deeply rooted was this conviction that for a number of years other makers regarded it as a fine thing to state that their microscopes were *not* made as was done in Jena, until a time arrived when makers hastened to state that they were produced on scientific principles *as in Jena.*

Such being, in those days, the spirit in which practice looked upon science, there must have dwelt an unusual soul in a man of Zeiss's grade of birth and culture. His insight and determination are all the more to be viewed with wonder when we bear in mind that he had failed in his first attempt and that his second essay under Abbe's guidance did not lead to immediately striking results, and that there was a reasonable prospect of one sacrifice following upon another and a possibility of time and money being exhausted to the ultimate point of ruin. If this had happened and if the ruined "Jena Optical and Scientific Instrument Works" had survived under the auspices of Messrs. Brown, Robinson and Jones, a historical reference to it might have taken the unimpassioned form: "Its former owner was a Carl Zeiss, who embarked upon risky ventures and thereby met his ruin." However, for the benefit of humanity, let it be said, Carl Zeiss did not perish in his "hazardous" venture. The "University Mechanician" rose to become the world optician, and, as we shall see later, he attained to even greater heights.

Ernst Abbe.

It was only natural that we should begin by surveying the person of Carl Zeiss as the founder of the great world-famed establishment which bears his name. Since more than a third of a century he numbers among those of whom it is said "De mortuis nil nisi bene", and if we have spoken of him nothing but good it is not because we wish to be loyal to an on old adage but because it is only thus that we can rightly speak of him.

But though Zeiss was the founder of the little workshop which eventually grew into the Jena Works, it is to Abbe, now also since years numbered among the departed, that we must turn as the real founder in a wider and nobler sense of what is now known to the world as a mighty industrial and sociological monument. Like Zeiss, Abbe was a good man, but he

was also a great man, so much so that a true account and interpretation of his life and work could not but resolve itself into an endeavour to exhibit the union of greatness and goodness into a perfect whole bearing richest fruitage.

If it be true that the world's largest optical works would not have been in existence if it had not been for the personality, the intelligence, and the character of its original founder, it is equally certain that the contributory influence of Abbe is an integral factor in the continuance of its existence, not only in the sense, as we already know, that Zeiss alone would not have been able to set his wings to reach such heights, but also in that other sense that it was by a sheer miracle of fate that Zeiss became associated with this above all men. For he might have searched the wide world over and not have found another who was so perfectly attuned to his great task, who so clearly fathomed its significance and bent his rare special gifts so wholeheartedly upon his envisaged goal. What instinct was it that prompted Zeiss to seek the genius whom he needed in his immediate neighbourhood instead of searching for him in vaster fields? Had he been a man of scheduled reasoning habits he might have adopted the obvious course of perusing a list of men of established reputation in scientific optical research and from their number, guided by the ring of a name, selected the most proficient. In that case, Abbe's name would assuredly not have figured in the list, for with optics he had had little to do excepting as a receptive student. It is, of course, futile to speculate on the altered course of imaginary events, but it is almost justifiable to assert that the results would not have been a shadow of the actuality. The justifying argument may appear a paradox, but the paradox vanishes on closer inspection. Abbe brought with him a most fortunate quality. He was wholly uninitiated in optical routine. This was a singularly important factor. For, while the great majority of problems affecting the progress of humanity demands the services of highly trained and experienced specialists, the very highest problems, which force us to reconstruct our fundamental aspect of things, stand in a significantly different category. Their solution demands, apart from general and deep scientific insight, minds which have not yet fallen under the sway of recognised systems of research or become narrowed in their visions by an excessive faith in authority. It is from this aspect that history can point to such pioneers as Faraday in electrical induction, Fraunhofer in the analysis of the spectrum, Robert Mayer in the conservation of energy. In Abbe's case the application of our argument proved no exception [1].

[1] A very interesting illustration of this view is afforded by the following fact. The great physicist Helmholtz likewise attacked the problem to which Abbe applied

But there is another point which affects not so much the intellectual as the human side of the matter. It is not everyone, probably not one among many, who is endowed with the requisite tact and patience to work in amicable relation with a man of an entirely different educational calibre and therefore also bound to view all things from a different angle and even to inspire him and all dependent upon him for new, unaccustomed, and seemingly quite unprofitable work. This could only be accomplished by a man who had the fine gift of benefiting to the full the cause he was serving by reason of his mental supremacy without making that supremacy personally felt in the remotest degree. There are chapters in the history of optical construction the tragic contents of which have been solely brought about by the practical man and the man of science having lacked the necessary qualities to permanently feel their identity of purpose in the great cause which they were serving. The relations which subsisted between Zeiss and Abbe furnish an inspiriting example of two extremely heterogeneous factors cooperating in untroubled harmony with superb results. It would be difficult to decide, what we ought to admire most, the fine sense of appreciation which ruled the conduct of the experienced man of business towards the young doctor or that of the richly endowed savant towards the plain practical man, both impelled by the one harmonious desire to attain their aim by mutual effort and perfect understanding.

* * *

We have hinted in bold outlines at the scope af Abbe's achievements in practical optics. We shall now endeavour to express ourselves a little more definitely in relation to his theoretical and practical influence upon the construction of the microscope.

We have already explained that the task which had been conceived was to elaborate a system which rendered it possible to predetermine theoretically by calculation all data required for the production of an optical combination in such a manner that nothing should be left to the

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his intellectual acumen, but he did not get beyond the realisation that theory collided with the discovered fact. There was a hidden error which he failed to discover, and it never occured to him that the whole base of the theory might be wrong. He was all the more astonished when he obtained knowledge af Abbe's work. Indeed, he journeyed expressly to Jena to have matters expounded to him in detail.

lens-grinder and constructing optician in the way of trial and error or retouching, and we have also been told that a wise policy of moderation induced Zeiss and Abbe to confine this strictly scientific system at the outset to optical formulae which satisfied very simple theoretical conditions of image-formation. These conditions obtain, as has been well known for a long time, when the pencils of rays are rendered very narrow by cutting off the extreme rays, that is briefly, by using narrow stops (or diaphragms). Now, when Abbe proceeded on the lines of this fundamental aspect, — that being the only one which then existed, — to calculate, to construct, and to observe, he found that the supposed fundamental theory was imperfectly true. He found that up to a point the images of microscopic objects did improve with increasingly narrower stops, but that as the stops were diminished beyond this point not only was there no further improvement, but the images became markedly worse, until finally no clear image formed at all, despite the fact that sufficient light passed from the object to the eye.

There was only one conclusion to be drawn from this. But he who would draw that conclusion required to be endowed with a degree of scientific independence and intrepidity which is not always to be encountered among highly distinguished men of science. Even Helmholtz, as we have seen, when he found that his theory did not accord with the observed facts, capitulated to the extent that he accepted the resulting inconsistency as something inexplicable. Yet all that was really needed was to boldly say that the entire and venerable theory of the formation of microscopic images was fundamentally false. So much for destruction. But what was Abbe able to do about the constructive alternative? — Why was the theory wrong, and what is the right theory? — Abbe supplied the answer in a manner which was little short of confounding, and it is significant of the man's character that, though he must have thoroughly realised the magnitude of the fundamental contribution which he held in his hand to make to science, he made no attempt to disclose what could not have failed to crown his name with richly deserved fame. Rather did he almost sedulously guard his trust, concerned only that the practical consequences of his discovery and conclusions should be brought to bear upon the development of the microscope. Thus it fell out that his doctrine, which came into being in 1870, was not enunciated to the world of science until much later. Great was the astonishment of those who witnessed the demonstrations of the theory at the Natural Science Meeting held at Halle in 1891 and there learned that these things had been known throughout the preceding twenty years.

It would carry us far beyond the scope and spirit of this book if we were to make an attempt to sketch in the merest outline the results of Abbe's investigations. But it may not be out of place to append a brief bibliography[1].

The New Glass.

So far we have only referred to the form which requires to be given to lenses in order that they may yield good images. But there is another factor which determines the course of the rays, and that is the nature of the material of which lenses are made. The utterly uninitiated might be disposed to think that nothing need be said on this head since the material in question happened to be just glass. In the first place, this is not an invariable fact, not even as a bald statement, though the vast majority of lenses are made of glass. The chief cause of the misconception lies in the use of the word "glass". When we say that a certain object is made of metal we are naturally asked to state what actual metal it is made of. We wish to know, is it iron, brass, or bronze. The word metal is a collective term which happens to cover, even in the popular mind, a great variety

[1] A short preliminary abstract of his theory was published by Abbe in 1873 in Max Schultze's Archiv für mikroskopische Anatomie. In 1881 a more extensive exposition was actually in the press, but it was withdrawn owing to Abbe's time and interest being completely absorbed by the new optical glass. So it happens that the first comprehensive, but on the other hand more or less popular exposition of the theory is contained in the second edition of Dippel's Treatise on the Microscope. — In this connection it may be noted that Abbe attached no particularly great value to the publication of his work and its results. This attitude was quite in keeping with his general outlook on things and it was also consistent with the spirit that urged him to be ever moving in the world of action. It must also be realised that at that time the world, and notably Germany, lacked suitable organs for the publication of such work as his, and neither was there a sufficiently wide circle of appreciative and qualified readers. It is gratifying to know that in more recent years this ever growing gap has been partly filled to a considerable extent and that there is every prospect of the endeavour being completed. This is being mainly achieved by a series of four works: (1) S. Czapski, Theorie der optischen Instrumente (also Vol. II of the Handbuch der Physik), Breslau 1893; second greatly revised edition by O. Eppenstein (Vol. VI of the Handbuch), Leipzig 1906; third edition in the press. — (2) Ernst Abbe, Gesammelte Abhandlungen, Vol. I, Jena 1904. — (3) Die Theorie der optischen Instrumente, Vol. I: Die Theorie der Bilderzeugung, etc., edited by M. v. Rohr, Berlin 1904; English translation by R. Kanthack, published on behalf of the Scientific and Industrial Research Department by H. M. Stationery Office, 1920. (4) Die Lehre von der Bildentstehung im Mikroskop, elaborated and edited by Otto Lummer and Fritz Reiche, Brunswick 1910.

of materials. Now, it is far less obvious that the same applies to the term *glass*. Glass forms by the intimate interfusion of minerals, acids, oxides, earths, etc., and the variety of the components which go to make glass is certainly quite as extensive as it is with metals. There are considerable restrictions in the choice of substances which may be fused together. In many cases crystals are formed, and it is a characteristic property of glass that it should be structureless, or devoid of crystallisation. In many other cases glass may result, but it may be useless for optical purposes because it may be of a kind which deteriorates, or it may be insufficiently homogeneous, or insufficiently transparent, or not sufficiently colourless. Despite these restrictions there are still thousands of possible combinations of substances the fusion of which furnishes optically useful glass.

This fact and its general knowledge notwithstanding, the catalogues of the glass works continued to present a very scanty assortment right into the nineteenth century. In fact, it is not incorrect to say that only two kinds of glass were made, viz. crown glass and flint glass, all made up of silica, soda and potash, with the addition, in the case of flint glass, of lead oxide as an essential constituent. Crown glass has the property that it imparts to a ray of light a small refraction as well as a small colour dispersion, whereas in the case of the flint glasses both phenomena, refraction as well as colour dispersion, are much more pronounced. In consequence of the addition of lead, flint glass is also denser and has a higher specific gravity. Hence it arose that within comparatively recent years the denser kinds of glass were also held to be the more highly refracting ones, and conversely. Several varieties of these two main classes were introduced with the object of maintaining a more or less continuous progression extending from the "lightest" crown to the "heaviest" flint and hence, according to the older restricted aspect, from the lowest to the highest refraction and colour dispersion, as indicated in fig. 7. Incidentally, it transpired that the colour dispersion was not very uniform in most cases, that is to say, the various kinds of glass gave rise to spectra the separate component regions of which exhibited dissimilar and unrelated widths.

It was soon realised that this range of available material was far too scanty for optical purposes; but the glass houses could not be prevailed upon to secure a greater variety in their products, nor need this surprise us, when we consider that the amount of glass required for optical needs was, and still is, negligibly small as compared with the total amount of glass produced, so that from a purely economic point of view further efforts appeared wholly unremunerative. The incentive would necessarily

have to come from the opticians themselves. Among these FRAUNHOFER must be accorded first place as the forerunner of the new era founded at Jena. Directed into the right course by the suggestions of a French Swiss named Guinand, he followed up his endeavours so successfully that he would in all probability have attained the desired end if his untimely death had not intercepted the harvest of his genius.

Efforts made in England likewise ran to seed, and so it happened that, when Abbe in conjunction with Carl Zeiss attacked the problem of the microscope, manufacture and supply of optical glass was in almost as backward a state as it had always been.

In his calculations Abbe frequently held in his hands the making of a superb microscope if only certain types of glass had been available for making one or the other lens. This applied in particular to pairs of glass having a similarly distributed colour dispersion throughout the spectrum, which would have rendered it possible to produce lenses giving entirely *colourless* images. Then also Abbe's heart longed for those kinds of glass in which a high refraction might be associated with a low dispersion, or vice versa, that is to say, having qualities unknown in the existing series of glass.

"For years", so Abbe relates in reference to his work with Carl Zeiss, "we combined with sober optics a species of dream optics, in which combinations made of hypothetical glass, existing only in our imagination, were employed to discuss the progress which might be achieved if the glass makers could only be induced to adapt themselves to the advancing requirements of practical optics". To test these ideas lenses were even made of *fluid media.* These could without difficulty be so chosen as to furnish optical qualities conforming to those of the missing glass. These experiments were very successful, but naturally they did not admit of any practical application. Their only practical effect was to intensify the wish for a laudable exertion on the part of the glass makers.

Otto Schott.

The glass makers, however, remained unmoved. They stubbornly continued to make those kinds of glass only which could be fused easily and conveniently, and they scheduled them in accordance with their specific gravity, just as if they were intended for use as ship's ballast, as Abbe satirised the procedure. Nevertheless, the time bestowed upon those academical dream studies was not lost, for they acted as an ever growing

incentive to give substance to "the stuff that dreams are made of", and with the progress of these studies the problems involved and their solution gained clearer and clearer shapes. Amidst all these inspirations and visions an exhibition of scientific instruments held in London in 1876 provided Abbe with an opportunity of writing a review of the position of microscopical optics at that time, in which he pointed out in emphatic terms of regret that the practical optician possessed all that was needed for the construction of all but perfect lenses. He had a well developed theory and a well tried technique, and all that was wanted was suitable material for the application of technique and theory. This review fell on deaf ears. And thus all progress might have died of inanition and apathy if salvation had not come from an entirely different side. The *deus ex machina* was a young man whose father possessed a plate glass factory in Westphalia and who already in his young days allowed his ideas to outgrow the jog-trot of the glass house. This was Dr. OTTO SCHOTT[1]. His first inspirations lay in the borderlands of mineralogical chemistry and his ultimate goal embodied nothing less than a comprehensive study of the chemistry of the igneous fluxes. Obviously the making of glass constituted only a fraction of the general problems which this involved, and initially Schott had no thought of the optical properties and their practical consequences. This side of the investigation did not occur to him as a paramount problem until he had succeeded in producing a new kind of glass, and until it so happened that he sent samples of these new lithium glasses for optical examination to the very physicist whom he wisely selected as the best authority. This happened in 1879, and Abbe in Jena was the physicist in question. Unfortunately, the results of the tests were negative. The lithium glasses had all too many striae, and when these had been eliminated by laborious efforts, it was found that the optical qualities, though new in their characteristics, were of precisely the opposite sense to those demanded to serve Abbe's program.

The inevitable discouragement of this first failure did not persist over long. Soon after, Schott embarked upon fresh experiments, and ultimately success resulted from the use of two new elements, boron and phosphorus, in the shape of the new famous borate glass and phosphate glass.

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[1] Otto Schott, born in 1851 at Witten, studied during the years 1870 to 1875 at Aachen, Würzburg and Leipzig, and graduated in 1875, the subject of his thesis being "Defects in the manufacture of window glass". He then occupied positions in chemical works and was employed in establishing glass houses in Spain. In the course of the last generation he has devoted himself to the development of the Jena Glass Works, which now employs about 1300 persons and covers a very wide range of operations.

Naturally, this first success did not overcome all difficulties. On the contrary, the real technical and economic problems had only been initiated thereby. It may be boldly asserted that the nature and character of Schott were an integral part of the forces which were needed to carry out the work through to its conclusion. When we consider that the advent of success was at best exceedingly uncertain and even then unlikely to bring more than a very modest reward, it cannot be doubted that what attracted Schott can only have been the problem itself, the fascination of achieving the solution of a hitherto vainly attempted problem. Those who are able to realise this aspect will not hesitate to identify Schott with Zeiss and Abbe in the bond of a creative idealism. We shall not be wrong in so doing, even though in the course of events, contrary to expectation, the manufacture of glass, carried on in the service of science, has proved to be capable of yielding material rewards. The events which led up to ultimate success make up a story of long and arduous trials, an account of which would tire the reader. We must content ourselves with a short sketch of a few landmarks in this significant development in scientific glass making. In 1881 Schott and Abbe joined in a scheme of cooperation. Schott continued at Witten the experimental melting operations, doing so at first on a very small scale, say one or two ounces at a time, but very carefully studying all the chemical constituents which might possibly give rise to vitreous fusions. Abbe, with the notable assistance of Dr. Riedel, then examined the resulting specimens with the spectrometer (fig. 6) specially invented or partly improved by Abbe. Very soon it was found that certain relations subsisted between the chemical composition and the optical properties, and this furnished the basis of a systematic continuation of the work. In 1882 Schott settled in Jena, and in cooperation with Carl Zeiss and Dr. Roderich Zeiss the experiments were prosecuted on a larger scale, and quantities were now produced amounting to as much as twenty pounds. This increased effort notwithstanding, an attempt to establish regular

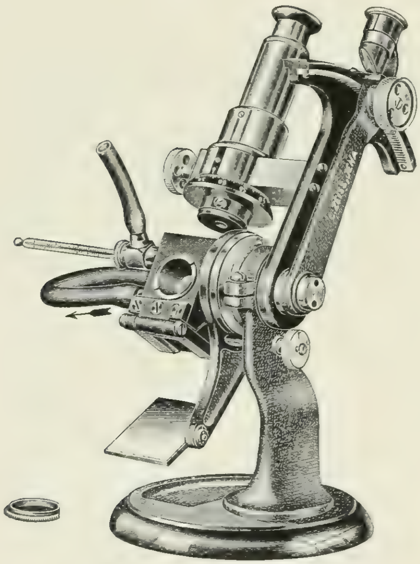


Fig. 6. The Abbe Refractrometer.

industrial working might have proved unavailing if at the instigation of Abbe and a few scientific and technical men of influence in Berlin (Carl Bamberg, Wilhelm Förster, Wehrenpfennig) the Prussian Ministry of Education had not provided for this express purpose a subsidy of £ 3000 paid in two annual instalments of £ 1500 each;[1] and it was perhaps a fortunate circumstance that at the head of the department was von Gossler, who was a staunch supporter of scientific and technical progress. This readiness to assist on the part of the government is all the more entitled to grateful acknowledgement since the offer remained in force even after the original condition attached to it, to the effect that the glasshouse was to be transferred to Berlin, had been rendered impracticable by Schott's refusal to sever his connection with Abbe in Jena. And at this time, if we look back and picture to ourselves how things might have turned out if the latest accession to the triumvirate had considered it a duty to himself to respond to the call of the metropolis and therefore had accepted that condition, we can only congratulate the world that things happened as they did happen. For, as events have proved, the joint efforts of Abbe and Schott, their mutual promptings and deliberations, have been attended with the most beneficent results, and it is difficult indeed in these days to dissociate the Zeiss Works from the Glass Works.

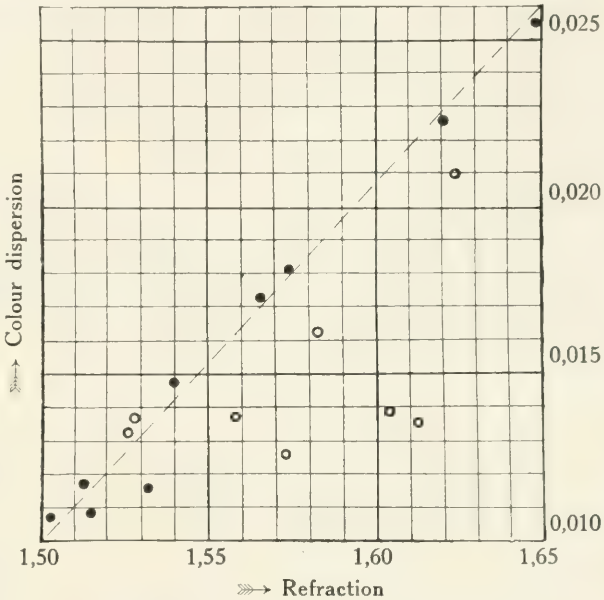


Fig. 7. Graphic comparison of the optical constants of the old and new series of optical glass.
• Old series (all near the diagonal).
○ New series of Jena glass (more or less away from the diagonal).

[1] There appears to be an impression among subsidised English glass makers, as implied in suggestions and suppositions, that this Prussian subsidy did not end with the original contribution. In view of these rumours the author wishes it to be clearly understood that beyond the one subsidy of forty years ago no further assistance has ever been granted.

The Glass Works of Schott & Co.

Thus it came about that in the autumn of 1884 the glasshouse was put into operation under the title "Technical Glass Laboratory of Schott & Co." ("Glastechnisches Laboratorium Schott und Genossen"). In 1886 already the firm issued its first catalogue of optical glass. It contained such a large number of new materials, notably baryta, borate, phosphate, and zinc glasses satisfying requirements of opticians in many and varied directions, that the list may be said to have signalised a new era, not only in the history of the microscope but of optical instruments and devices in general.

It is not practicable to here describe in detail the development of the productive capacity of the glasshouse, and all we may attempt is to sketch a few main features. Incidentally, it may, however, be mentioned that in

Fig. 8. The Jena Glass Works as it appeared in 1911.

the matter of *output* the strength of the establishment has long since shifted from optical glass to other products in much wider demand, such as cylinders and other bodies of glass, thermometers and other tubular glassware, laboratory glassware of special resisting qualities against the effects of sudden changes of temperature, etc.[1]. Nevertheless, the establishment has not only remained faithful to its original purpose, but it has even extended the production of optically valuable glass in various significant directions. Recently, in particular, it has paid attention to three new problems, the two first of which have been solved more or less completely, whilst the third is well on the way. All these relate to the transparency of glass to rays of light, but the nature of the transmitting qualities present different aspects in the three problems. The first relates to the production of special kinds of glass which are colourless in a higher sense than the glass

[1] An account, at least as regards the older period, is given in H. Hovestadt's book, "Jena Glass and its Applications", translated by J. D. and A. Everett, 1902. The subject is also treated in a fascinating manner by E. Zschimmer in his book entitled "Die Glasindustrie in Jena" (with drawings by Kuithan), Jena, 1909.

hitherto obtainable, inasmuch as they transmit all rays of the spectrum in an equal degree. Ordinary crown glass is invariably slightly greenish and flint glass is always of a yellowish tint, and the older products of the Jena Glass Works were likewise tinted in a more perceptible degree than is desirable for many purposes. Certain vitreous mixtures of the nature of boro-silicate and baryta glasses have now been successfully reduced to glass which may be described as colourless in the highest degree. An endeavour to solve the second problem has enabled Dr. Zschimmer to produce types of glass which, apart from their behaviour towards visible rays, possess remarkable properties with respect to those rays of very short wave-lengths which are situated beyond the visible spectrum and which therefore are known as *ultra-violet* rays. The previously known kinds of glass absorb these rays to a very large extent, whilst the new glass transmits them relatively freely. This renders them in many cases eligible to compete with the material of natural crystals hitherto used for this purpose, for instance in photography. In this way the new glass may be used in the place of quartz or fluorite, over which it has many advantages, quite apart from the question of price. When we come to pay attention to the astronomical section we shall have to say more on the subject. The third problem relates to glass which possesses singular properties in precisely the opposite direction. It embraces *coloured glass* endowed with definite optical characteristics. Coloured glass exists in large quantities. But the problem to which we refer is concerned with certain types of glass which sift out of the spectrum certain regions, one glass one particular region, another another region, and so forth. This investigation, which is still in progress, promises to yield rich material for advances in photography in natural colours, and likewise for many other purposes. Among the material which has already resulted from these endeavours we may mention a new red filter, the Jena yellow isochromatic screens, the blue-uviol glass for the Lehmann filter, etc. (see the makers' new catalogue of coloured glass).

The chief difficulties which are to be overcome in the manufacture of new glass of this nature arises from the fact that, in addition to the required qualities, the glass may acquire properties of an undesirable nature. If these happen to be injurious, they must needs be removed or the glass will be useless. One of the defects of this kind is the formation of striae, which arises from want of uniformity in the material. Another is a diversity in the stresses sustained by the material, which may be sufficiently intense to cause the glass to crack. The resulting strained condition can be removed only by reheating the glass and allowing it to cool extremely slowly and gradually. This is one of the operations which have been

greatly improved in the course of time at the Jena Glass Works. The electrical annealing process devised by Zschimmer is the last word in this respect. There are, however, defects which do not impair the optical qualities of the glass, and these should rightly be regarded as cosmetic blemishes only. This remark applies in particular to small bubbles contained in the glass, whose presence is absolutely unavoidable in the manufacture of certain kinds of glass, but which do not exercise the slightest effect upon the performance of astronomical, photographic, and other instruments.

The Zeiss Works.

By briefly referring to the history of the Glass Works, before doing the like with the Zeiss Works as the primary undertaking, we have not observed, me must frankly admit, the ordinary and logical rules of sequence. But it was intelligibly useful to do so. We will now fill up the deficiency.

The development of the great establishment may be well visualised by distinguishing three periods: — The first is that extending from 1846 to 1872, which covers the firm's childhood, as it were, and which terminated with the materialisation of Abbe's theory. The period of maturity began in 1889, and the intervening period from 1872 to 1889 was a transition period. This was a period of active developments in that it witnessed the full technical elaboration of the microscope, including the introduction of the homogeneous immersion objective in 1879 and that of the apochromatic objective in 1886. This same period brought about great changes in the system of manufacture. The original *workshops* became an *organised factory,* and the whole range of practical optics spread its wings over the solitary microscope, which until then had been the one engrossing speciality of the firm's activities. It naturally became imperative at that period to discover men qualified to take part in the general commercial and technical management, for in the event of Carl Zeiss exhibiting signs of infirmity or illness Abbe would have stood alone. It had also to be taken into consideration that the time was fast arriving when the directing mind of an undivided establishment would have to be replaced by the heads of independent departments. The first two men to be named in this connection are Roderich Zeiss and Siegfried Czapski, neither of whom are now among the living, and after these the members of the present board of management.

RODERICH ZEISS, the son of the founder, organised the working of the establishment on a commercially productive basis, and he took an active

part, though only for a short time, in the technical expansion of the undertaking. He retired in 1889.

SIEGFRIED CZAPSKI, when still a young man, transferred himself from Berlin to Jena on the advice of Helmholtz. Immediately after entering

Fig. 9. Professor Siegfried Czapski (dec.).

upon his duties as Abbe's private assistant he met the problems set before him with such complete understanding as to arouse in Abbe the conviction that in Czapski he had found the man who was destined to assist him effectively and independently in the direction of the rapidly growing undertaking. This conviction was justified to a degree which merits

unstinting acknowledgement, for his position and duties were frequently thankless enough. Other leading members of the staff might have their names identified with certain duties and successes, but this was rarely the lot of Czapski, and yet he had an active and decisive share in nearly all that has made the firm great. Moreover, he did an immense amount of work of momentous significance which does not appear on the surface, for next to Abbe he was endowed with the clearest insight into the scientific fundamentals of all the incidental problems.

It was indeed this complete grasp of the subject which enabled him to give the first comprehensive exposition of geometrical optics in terms of Abbe's conceptions. He, too, is responsible for much relating to the technique and organisation that rendered it possible to carry through the application of Abbe's ideas. It goes without saying that with the creation of the present organisation he joined the board of management. Who could have predicted that only a few years later he was fated to be removed by the hand of death in the very height of virility!

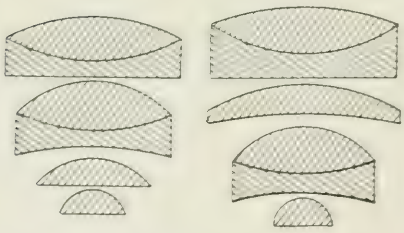
The following constitute the present board of management:

Dr. (hon.) Max Fischer (Commercial),
Prof. Dr. Rudolf Straubel (Physical science),
Dr. eng. Walter Bauersfeld, August Kotthaus } Technical.

The Microscope Department.

We will now survey the various sections into which the present organisation is divided, since craftsmanship has made way for a highly developed and specialised factory organisation.

We naturally begin with that department which originally embraced the whole of the undertaking and of which we have already heard a good deal, that is to say, the Microscope Department. Great is the advance in microscopy which this section has to its credit, quite apart from the fundamental and wholly revolutionary pioneer work done by Abbe, whereby the production of a perfect microscope ceased to be a mere problem of the refraction of rays of light but became also a problem involving diffraction



Figs. 10 and 11.

Two forms of homogeneous immersion lenses consisting of four components (magnified four times).

or wave motion. The following practical achievements may be mentioned as special landmarks in the history of the microscope.

1. *The principle of so-called homogeneous immersion.* In passing from the microscopic object to the front lens of the objective the rays of light have to traverse two distinct media; first, the cover-glass, which is indispensable for safeguarding the objective as well as for the protection or treatment of the object, and the stratum of air between this cover-glass and the objective. This greatly interferes with the quality of the image. It causes a certain loss of light, it impairs the clearness of the definition, and is responsible for disturbing internal reflections. These conditions can be obviated by substituting a fluid medium for the intervening air. Water was introduced for this purpose (by Amici in 1840, Hartnack in 1855), glycerin (by Gundlach in 1867) and various oils (by Amici in 1869). It may, however, be done much more perfectly by means of a fluid having the same refractive properties as the glass (i. e. the cover-glass as well as the glass which forms the front lens of the objective), by using a fluid which is optically identical with the glass. Objectives

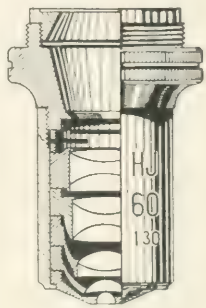
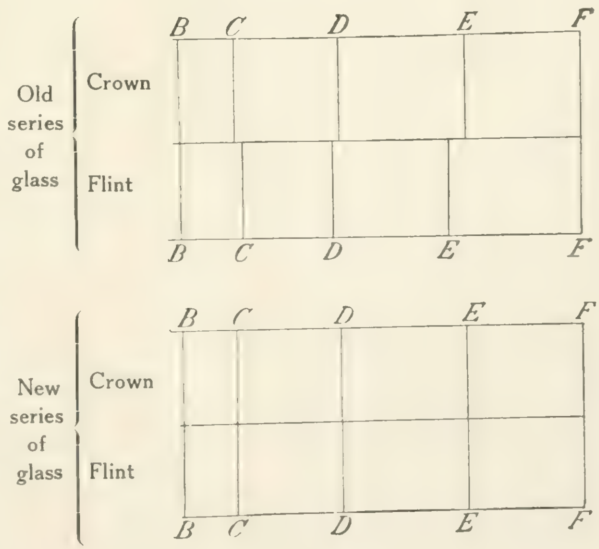


Fig. 12.
An apochromatic objective (consisting of ten lenses).

Fig. 13. The spectra furnished by the two specimens of glass are identified by the lines extending from B to F. Two of these lines, in our case B and F, can be rendered coincident by the appropriate choice of a prism angle or by the curvatures of the crown and flint glass lenses. When this is done the new glass typified in the diagram will also cause the C, D, and E lines to coincide; but this will not happen in the case of the glass of the older series, and it is this latter discrepancy which gives rise to the "secondary spectrum" with its undesirable effects.



constructed on this principle are known as "homogeneous immersion" lenses, to use a term invented by Stephenson and Abbe in 1878, and by way of distinction from the so-called "dry" lenses and other immersion lenses. The oil introduced by Abbe and universally used for this purpose is cedarwood oil.

2. *The apochromatic objectives* (originated by Abbe in 1886). The colours seen through a single lens in consequence of prismatic colour dispersion, which is inseparable from refraction, are more or less completely removed by the use of what are known as *achromatic* lens combinations made up of a crown lens and a flint lens. But the remedy is not complete. There still remains a residue of colours which do not belong to the object, and this residue is known as the secondary spectrum. Now, we know already, how the new types of glass afford a means of achieving further improvements in this respect. Lens combinations of this kind were called by Abbe *apochromatic* lenses, since they practically "remove" the secondary spectrum and the chromatic difference of spherical aberration; and with the additional aid of special compensating eyepieces this improved result is achieved throughout the field of view, including its eccentric or marginal portions.

An apochromatic microscope with a homogeneous lens furnishes a microscopic image of a degree of brightness, sharpness of definition, and absence of distortion and colour which previously did not belong to the realm of realisable possibilities. The make-up of such an objective is somewhat complicated, seeing that an objective of such a microscope, of which a typical example is shown in fig. 12, contains in general not less than ten components, some of which are separated by an air space, whilst others are cemented together in doublets and in triplets. The ideal properties of the new kinds of glass which have rendered it possible to construct these objectives will be apparent from fig. 13. This apochromatic type of lenses embodies, however, a further extension of the material employed in that it includes lenses which are not made of glass. In some instances a natural substance, fluorite, takes the place of glass. This is because fluorite possesses certain optical properties which it is impossible to reproduce by any artificial vitreous fusion. Now, fluorite in the shape of coarse material is widely distributed in the earth's crust; but it is a very troublesome matter to secure optically good and clear pieces. At the instigation of Abbe a special system of prospecting was set on foot in Switzerland, in which he took a personal share. It was this endeavour which first brought him in touch with a land which subsequently became his favourite holiday resort.

One of the special difficulties encountered in the making of microscope objectives is the process of centring the small lenses in their mounts. Formerly it was customary to connect the components by means of screw threads. It was, however, discovered that this gave rise to defective centration, which could only be partially removed by various expedients. For this reason a form of cylindrical mount was introduced in the Zeiss workshops in which the component lenses are mounted in rings having a very exact outer diameter. Later it was ascertained that this very method had been attempted in the middle of the last century by an optician of Eisenach of the name of Hasert, but evidently the then available technical resources were insufficient to put the idea into practice, and it was at Jena that it was first applied with success.

3. *The Abbe illuminating apparatus or condenser* (fig. 14). With all its simplicity this device is one of Abbe's epoch-making inventions, so much so that for a long time it was known in England by the shortened name "the Abbe". Its function is to cause light as much as possible to enter the objective from all sides. This not only has the effect of increasing the intensity of the light but, as must follow from Abbe's theory, it also ensures a much better microscopic image than could formerly be relied upon.

4. *Material improvements in the design of the microscope stand and its object stage.* The object of these improvements was to render the fine movements of the tube and the displacement of the object much more reliable than it had been, and at the same time to ensure absence of interference by these motions with observation in a large field. An essential requirement of a slow motion is that it should be free from irresponsive motion within a fairly wide range of temperature. As a rule, a screw is employed to impart motion. This has the disadvantage that the small discrepancies between the screw and its nut require to be annulled by the introduction of a fatty medium, and fat is only too readily affected by variations of temperature, so that the motion is

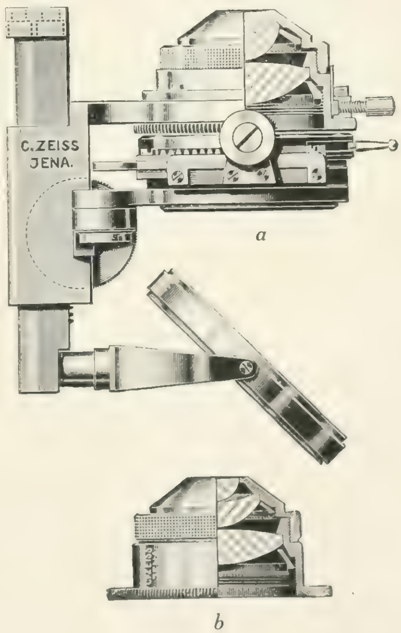


Fig. 14. Abbe Illuminating Apparatus.
a two-lens condenser,
b three-lens condenser.

not so reliable as might be desired. For this reason the micrometer screw has recently been replaced by a form of tooth wheel transmission devised by Meyer. This has the advantage that tooth-wheels can be made with greater precision; secondly, no grease requires to be introduced between the tooth-wheels; and, thirdly, in tooth-wheels, far more completely than in screw-threads, perfect contact on one side can be enforced by spring pressure, whereby all play of motion may be completely obviated. Fig. 15 shows a large microscope stand, which is likewise adapted for photographic work, and fig. 16 shows the new Stand, Model B.

5. *The binocular microscopes.* For scientific purposes observation with one eye will always maintain its supremacy, both in microscopic and telescopic vision. There are, however, many cases where it is desirable to be able to observe with both eyes, and this is notably the case when an object is to be viewed in its natural solid relief, or stereoscopically, as we say. We shall later have to say something about the means which have been devised to artificially accentuate this stereoscopic effect. We are not concerned with this exaggerated effect at present. We are merely concerned with the devices by which the purely surface impression which is all that a single eye can receive may be rendered more or less plastic. This is achieved with the aid of binocular microscopes. The effect may be realised in two ways. In the *Abbe stereoscopic eyepiece* of 1881 it is done by causing the pencils of rays proceeding from the object to pass through a prism before they can reach the eyepiece and thereby splitting them up into two distinct pencils. If both these pencils be allowed to enter the eyes in their entirety the ordinary flat image effect will result, but when one half of either pencil is intercepted by semicircular stops a stereoscopic effect will be produced. There is another and much more radical solution of the problem. This consists in combining two complete microscopes in twin form, as shown in fig. 17, and a special device, known as the Porro prism and to be described later, enables both eyes to look without strain through the two microscopes and to fuse the two images into a single stereoscopic image.

More recently special types of eyepieces have been introduced in which the transmitted pencil of rays can be split up into two branches to serve special purposes. This is accomplished by the introduction of a semi-transparent or semi-reflecting film of silver. In this category we may mention the binocular tube attachment for microscopes, which bears the fancy name "Bitumi", a double eyepiece, and a comparison eyepiece. The first named attachment is essentially a simplification of the Abbe stereoscopic eyepiece and enables one, by the use of half stops, to obtain a

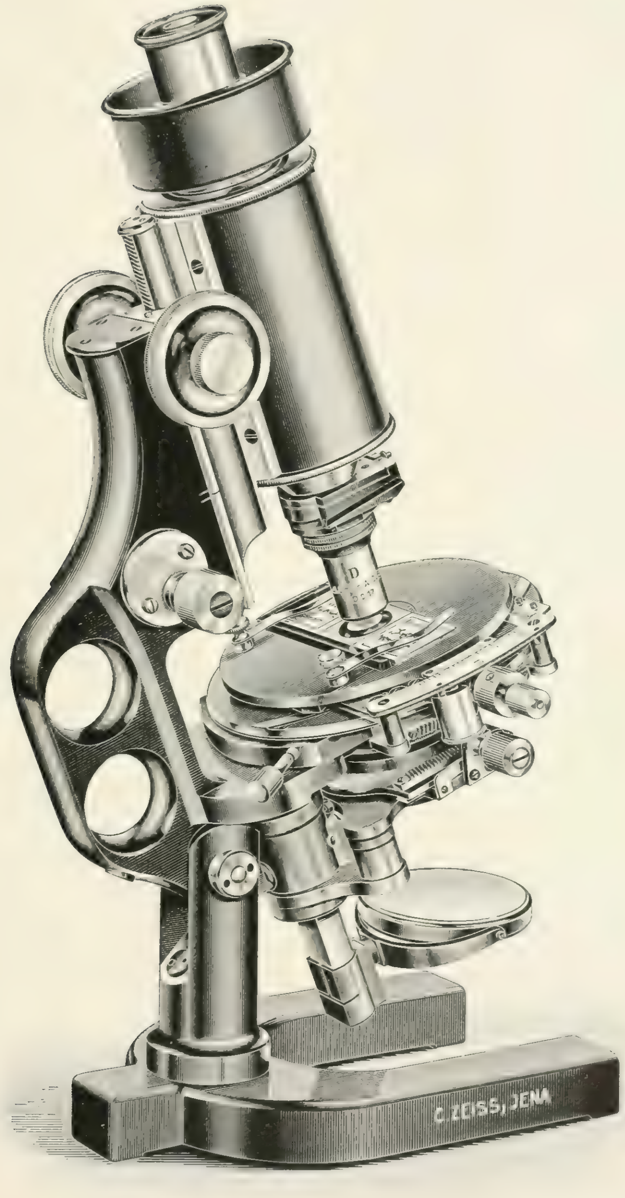


Fig. 15. Microscope Stand for viewing objects as well as for photo-micrography and projection.

stereoscopic effect with only one objective in use. The double eyepiece enables two observers to jointly view one and the same preparation under any magnification. The comparison eyepiece serves to unite two different images furnished by two distinct microscopes in the field of view of a *single* eyepiece. It may be interesting to mention that with such a device as the binocular "Bitumi" attachment the well-known *Brownian movements* of smallest particles in emulsions, suspensions, and colloidal solutions may be demonstrated in a much more pregnant manner than can be done without it, since the depth component becomes much accentuated, so that the zig-zag course of the particles appear much more striking.

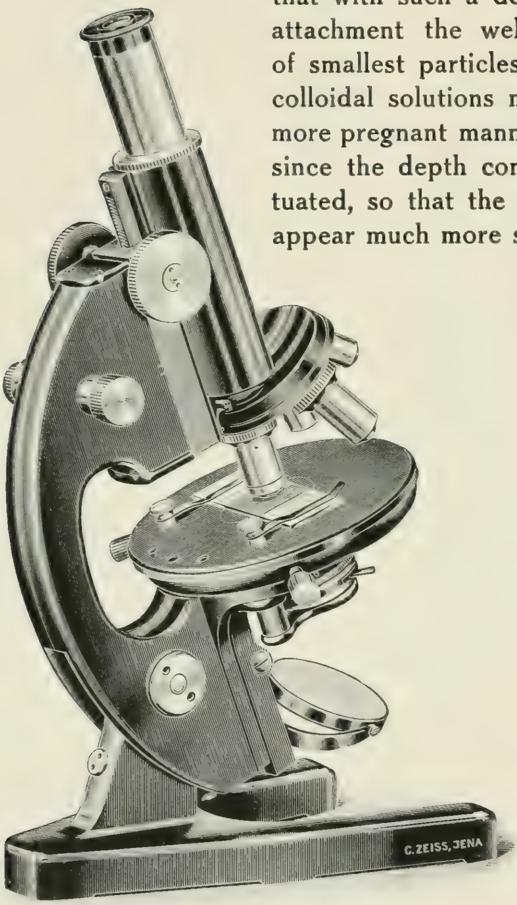


Fig. 16.
New simplified and progressively extensible microscope.

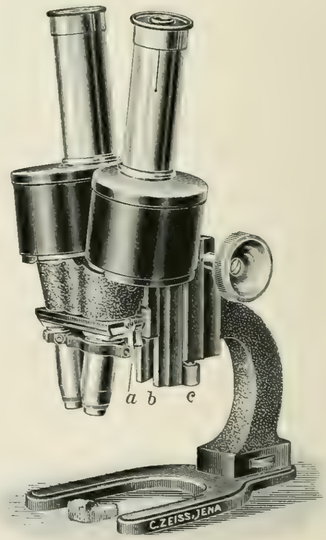


Fig. 17.
Greenough Binocular Microscope.

6. The microscope section comprises a very large number of allied and *accessory appliances*, such as the apertometer, various forms of drawing apparatus (fig. 18), dissecting and mounting stands, counting and measuring

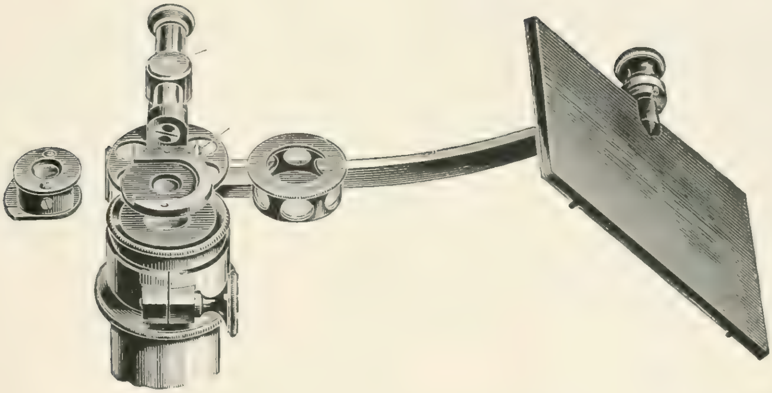


Fig. 18. The Abbe Drawing Apparatus.

devices, apparatus for working with spectroscopically decomposed or polarised light, also for observation at elevated temperatures (thermostat microscopes), complete apparatus for observing and projecting liquid crystals, and many others.

This section of the establishment holds a very interesting possession. This is its *historical collection* of microscopes, for which it may be claimed that it contains representatives of all principal types which mark the development of the microscope within the last three hundred years. This collection, quite apart from its value to the scientist and technologist, is exceedingly interesting to the art historian, for, though the design of a microscope is necessarily determined by its narrowly defined purpose, yet in every type the style of its period finds its unmistakable echo.

We must not omit to mention the micro-cinematographic apparatus devised by Prof. Siedentopf (fig. 19), which he uses since 1911 in his micrological laboratory for obtaining cinematographic records of microscopic objects. His experiments go back to the year 1907, but these earlier investigations were made with a simpler apparatus.

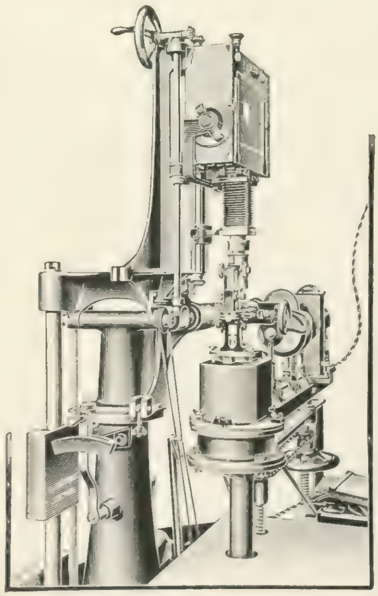


Fig. 19. The Microkino.

On the occasion of the centenary of the German Natural Science and Medical Association, which was held at Leipzig in 1922 an apparatus designed at the Zeiss Works in accordance with the ideas of Janse and Péterfi was demonstrated to the gathering. This apparatus was called a "Micromanipulator" (fig. 20). It has various screws and slide fittings, with

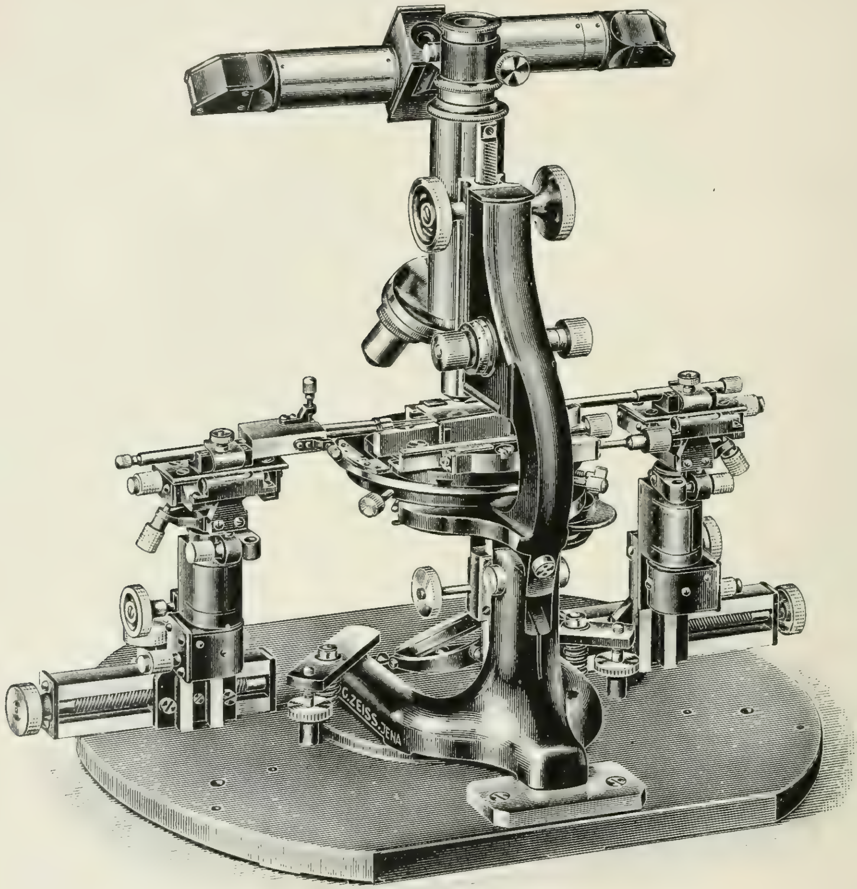


Fig. 20. The Micromanipulator.

the aid of which extremely fine glass needles and pipettes can be operated with exacting precision in all three directions of space within the limits of the microscopic field of view, and the smallest living organisms, bacteria or cells can by its means be separately manipulated, operated, aspirated, injected or submitted to certain chemical or physical influences. The object

which is to be examined is contained within a hanging drop attached to the under surface of a cover-glass within a glass chamber which is open at the side. This so-called "moist chamber" with the object contained therein is placed upon the microscope stage, and by means of the screws of the manipulator the observer, while looking into the microscope, is able to bring the fine glass needles or pipettes to bear upon any particular element of the object. Inanimate objects, such as fibrils or crystals, can be manipulated under the microscope by this means. It is hoped that the new method may disclose new facts relative to the processes of life which are now engaging the attention of biologists and also pathologists and bacteriologists.

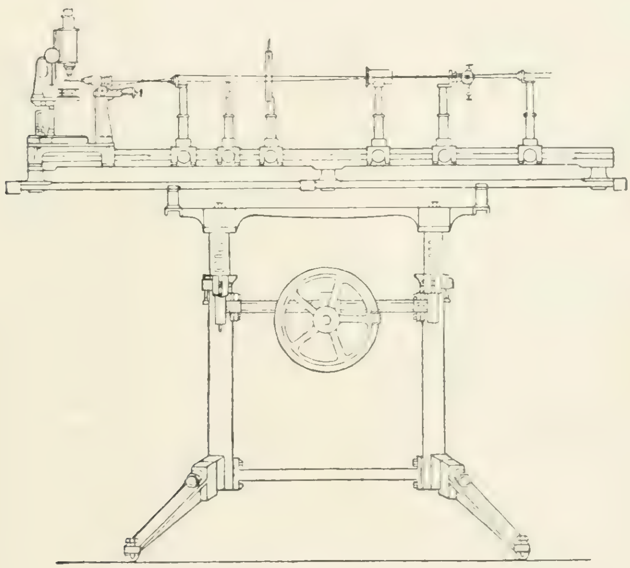
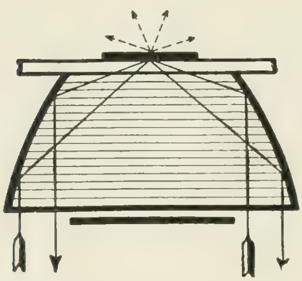


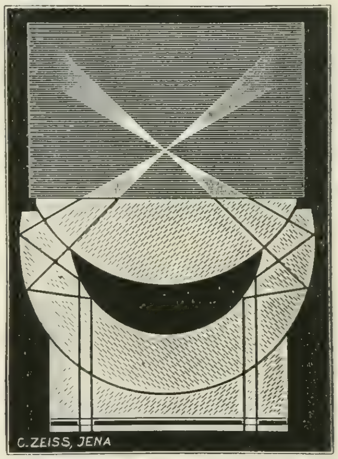
Fig. 21. The Slit Ultra-microscope of 1903.

To further extend the resources of the microscope a method was devised which has led to the introduction of an arrangement known as an *ultra-microscope*, a complete form of which is shown in fig. 21. This apparatus was originally devised by Siedentopf with the co-operation of Zsigmondy. No one conversant with the theory of microscopy need be told, of course, that the arrangement does not exceed the limits of microscopic magnification enunciated by Helmholtz and Abbe, though in another sense it does carry our vision much further. It does so by dispensing with the actual formation of geometrically similar images of minute objects and

only aims at bringing them into the range of visibility. What we see through the apparatus are not the particles themselves but rather their diffraction discs. These are seen by reason of a peculiar very intense method of illumination which gives rise to very pronounced contrasts on the principle of the so-called dark-ground illumination. The latter has been known to microscopy since 1837, but the methods of applying it had remained undeveloped. In the form in which it is applied to ultra-microscopy the object is illuminated from the side, as will be seen from fig. 21, and the optical system employed for this purpose is pretty complicated. However, this is not the place to explain it in detail. The method is applicable to particles whose linear dimensions range from about 6 to 250 units of a millionth of a millimetre (or from $2^1/_4$ to 100 units of the ten-millionth part of an inch).

The ultra-microscope was first described in 1903 in the "Annalen der Physik". Already within the very first years it evoked wide-spread interest





Figs. 22 and 23. The path of the rays in the Parabolid and Cardioid Condensers.

in the various departments of physical chemistry, biology and medicine. The ever increasing range of its application to research led to its further development, to modified devices, and to simplified forms, by which its power of performance was still further enhanced in several instances. The parabolid condenser (fig. 22) furnishes a faultless dark-ground illumination for the requirements of bacteriological observation, and it provides an excellent means for the observation of living bacteria without making any great demands upon the skill of the observer. When employed in conjunction with a hand-feed arc lamp operated by a continuous or alternating current of 4 ampères, it provides an ultra-microscope which is

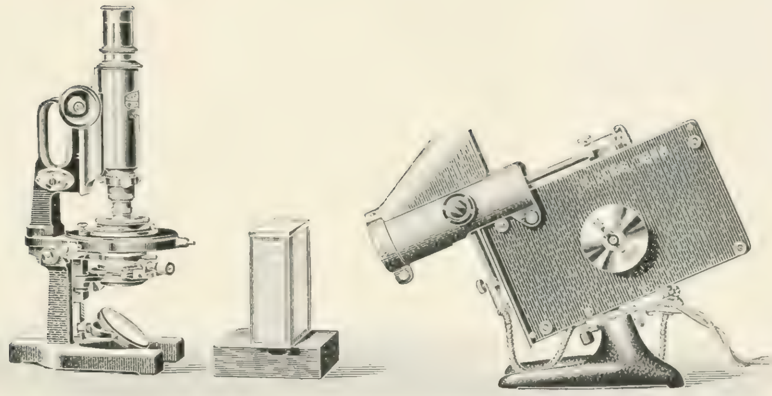


Fig. 24. The Cardioid Ultra-microscope with hand-feed arc lamp.

as simple as it is efficient for general bacteriological investigations. This arrangement has been employed to produce the very instructive cinematographic records of living protozoa obtained by Comandon, Siedentopf, Scheffer and others.

When the ultra-microscopic method of observation is to be applied to refined investigations in colloid chemistry the cardioid condenser (fig. 23) takes the place of the paraboloid condenser. In the former the rays are brought to an almost perfect aplanatic focus, and an extraordinary intensity is obtained by employing arc light or direct sunlight (fig. 24).

Solid colloids, from their nature, can only be studied successfully with the aid of the original arrangement as embodied in the slit ultra-microscope.

Optical Projection and Photo-micrography.

We have now arrived at a subject which, as the superscription suggests, forms a bridge from microscopy to photography. In both cases, whether we throw upon a screen an optical image of an object, or whether we photograph the magnified image of a microscopically small object, we do not view the images formed by the instrument

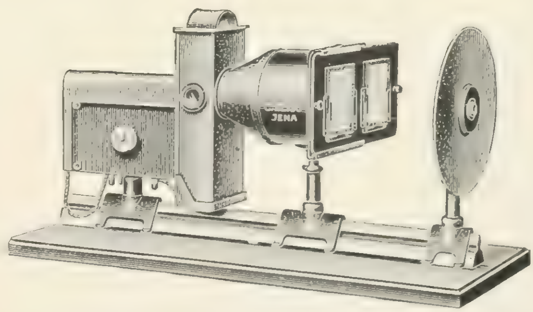


Fig. 25. Small Projection Apparatus with arc lamp, which may be connected to any domestic supply.

directly with the eye but we cause it to appear on a plane surface, to be viewed on a wall or projection screen in one case, on a ground glass focussing screen to be chemically fixed in the other; and in this respect both modes of demonstrating objects are closely allied to photography.

Fig. 26. Image of the human hand projected on a screen with the Episcope.

One characteristic component of the microscope, the eyepiece, is entirely absent in both procedures, or at all events it loses its original significance and rather plays the part of a second objective by reason of its modified construction. On the other hand, both operations belong to the domain of microscopy inasmuch as they furnish magnified pictures and not, like photography, reduced pictures of large objects.

At the Zeiss Works the subject of optical projection, in view of its immense value in scientific and popular education, has received unremitting attention since a great number of years. Since the first energetic impetus was given to it by Dr. Roderich Zeiss the ever widening problems which arose as the requirements became more and more exacting have now been solved in a manner which almost precludes the possibility, one would think, of further progress, if experience throughout the various sections of the establishment had not again and again nullified any such attitude of faith

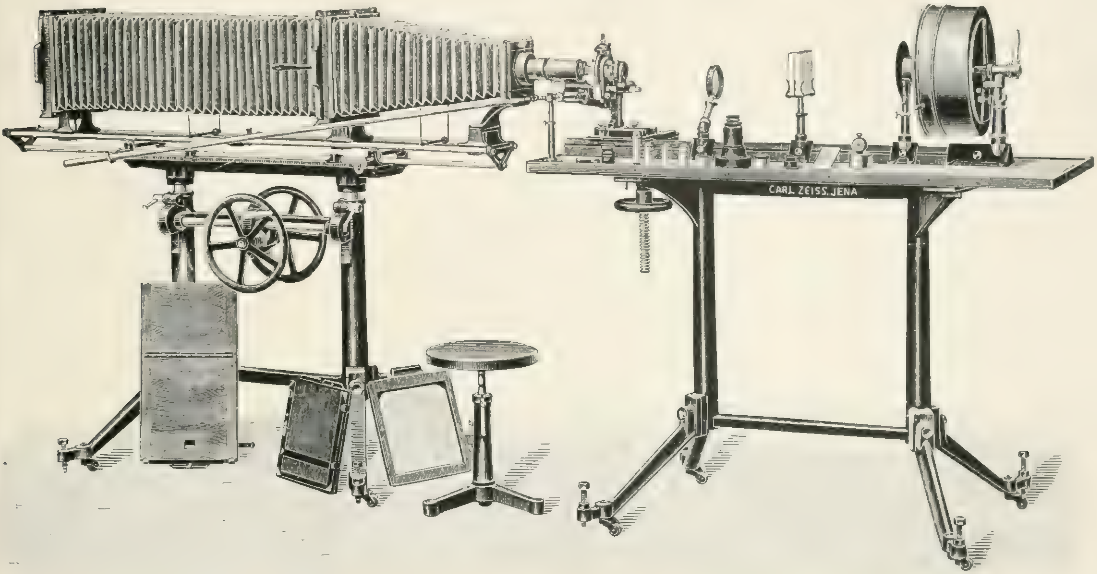


Fig. 27. Large Photo-micrographic Apparatus.
The detached table stand (on the right) with its components can be used independently of the camera as a micro-projection apparatus.

in final perfection. We cannot go into the various items included in this section, amongst which we may name the large projection apparatus, the double projection apparatus, the small projection apparatus (fig. 25), changing devices with revolving carriers or slide motions for quickly interchanging lantern slides, etc. There is, however, one achievement which should not be passed over in silence. This is the complete systematic elaboration of the twofold problem of projecting on a screen transparent objects and also opaque objects, the former by transmitted light, the latter naturally by incident light reflected from their surfaces. Long continued

experimental studies of these two modes of projection, known as *diascopic* projection and *episcopic* projection, have ultimately resulted in an apparatus named the *Epidiascope* (fig. 26), which is so designed that it is at a moment's notice available for either mode of projection. The pictures obtained with this apparatus are perfectly sharp and stand out in solid relief, and moreover the colours of the object are reproduced with such natural faithfulness that, once seen, their impression remains indelibly in one's memory. If the initial outlay for such an apparatus is indeed considerably higher than the cost of the ordinary so-called optical lantern, it must on the other hand not be overlooked that the difference is rapidly made good by the circumstance that in the place of costly slides, which in many cases are

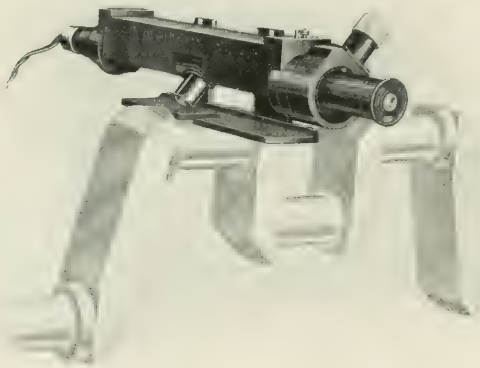


Fig. 28. Material Testing Microscope as applied in the examination of a crankshaft.

difficult to procure, any photograph, paper picture, print, drawing, illustrations in books, or the very objects themselves may be projected. For this reason it is finding its way increasingly into the lecture theatres of scientific and other associations, colleges, museums and like institutions. Recently its value has been still further enhanced by appending an attachment for the projection of microscopic preparations.

Recently optical projection has come into much use in an entirely new direction. At the Zeiss Works the method of optical projection has been in use for years as a means of examining mechanical parts requiring an especially exact finish, such as fine tooth-gearing. In view of the excellent results achieved in this way various forms of apparatus of this kind are

now made in the ordinary commercial way. It may be anticipated that extensive use will be made of this method as a means of ensuring the highest degree of precision in the machine-tool or the product.

A *photo-micrographic apparatus,* of which there are several forms, naturally consists of an illuminating apparatus, a microscope or an optical combination equivalent to it, and a camera. The apparatus as a whole is either horizontal or vertical. There is also a *Combined Horizontal and Vertical Camera* which can be used in either position. We shall not attempt to describe the various large and small designs of the apparatus (figs. 27 and 29) or their use in the study of organic and inorganic objects, such as specimens of polished metals, crystals, minute organisms, etc. A new design may be briefly mentioned. This is a small photo-micrographic camera for taking small photographs measuring $6 \times 4^1/_2$ cm. and provided with a special photographic eyepiece originated by Siedentopf. As will be seen from the illustration, it can be attached to any microscope stand in the place of the customary eyepiece. The microscopic image forms exactly in the plane of the photographic plate, where it appears magnified five times. The image-forming rays are partly deflected by a rectangular prism into a horizontal tube at the side, where another prism deflects the rays obliquely upwards, so that the image may be viewed through the eyepiece whilst the photographic exposure is proceeding. The small negatives readily admit of magnification. This apparatus not only greatly simplifies the procedure but also greatly lessens the cost of obtaining simple photo-micrographic records.

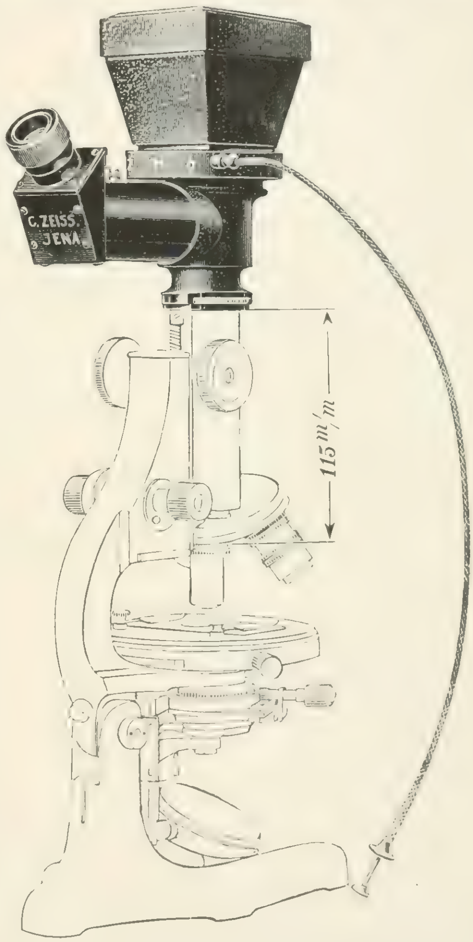
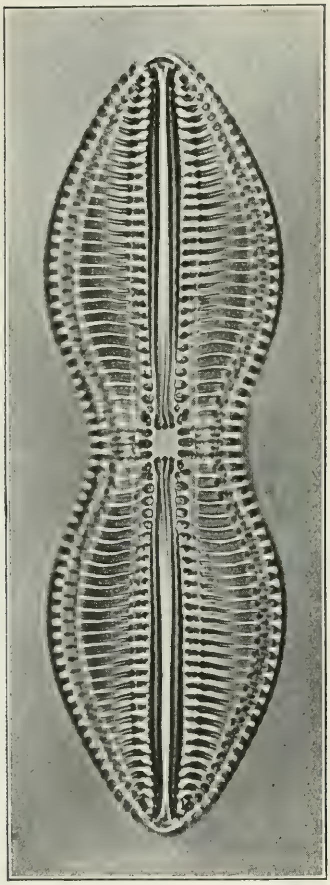


Fig. 29. Small Photo-micrographic Camera with Eyepiece.

We must not overlook the application of microscopy to the examination of metals, which is growing more and more extensive both in the science known as metallography and in technical operations. Obviously, prepared specimens can only be examined by incident light with the aid of a so-called vertical illuminator. Also, for such simple examinations as they present themselves in engineering works and many other workshops and for use in factories where the facilities afforded by a well equipped microscope laboratory are not at hand a simple and heftily designed microscope has now been brought out, which attaches directly to the work, often without any preparation, as shown in fig. 28, and which may be described as a portable *material inspection microscope.* It has been specially designed for this purpose and is provided with an adaptable attachment fitting. — Figs. 30 and 31 are reproductions of photo-micrographs to illustrate the significance of records of this kind.



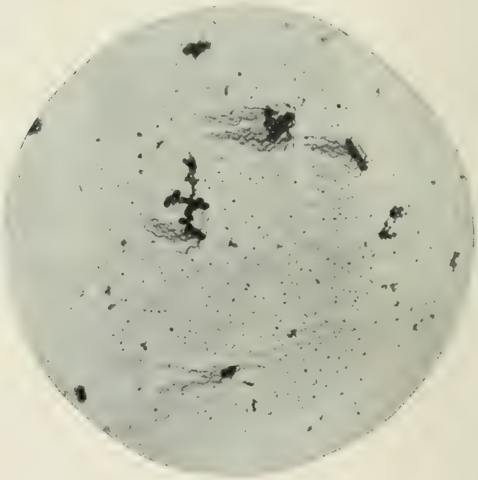


Photo-micrographs.

Fig. 30. *Navicula carbo* (magnified 500 times).

Fig. 31. Typhoid Bacilli (magnified 1000 times).

In order to enable those who are not completely conversant with the subject to appreciate the full significance of photo-micrography it will be well here to explain a fundamentally important point.

Fig. 32. Photo-micrographic apparatus for ultra-violet light.

To the uninitiated the sole purpose of a photo-micrograph would very naturally be to permanently fix in the form of a graphic record what can be seen in the microscope in order to be able at any time to refer to such a record long after the object has ceased to exist, or to reproduce it at pleasure for transmission to others. There is, however, another aspect which is not likely to occur to the tyro. This other significant quality of the photo-micrograph is that it discloses elements which the eye is unable to perceive in an otherwise equivalent microscope. This is to be accounted for in the following manner. We have already seen in the case of the microscope that the unqualified assumption that light is made up of *rays* does not meet the requirements of modern practical optics. It behoves us to go more deeply into the nature of things and to bear in mind that rays are a geometrical fiction and that in reality we are concerned with *waves* of diminutive length, but varying in length for the different kinds of light

which we call colours. The possibility of magnifying objects to a greater and greater extent, so as to obtain images which are geometrically similar to the object encounters an insuperable limit. This happens at that point where the elements of the object which are to be distinguished become so small that they are comparable to the wave-lengths themselves, and when this is the case the waves become confused by diffraction and mutual interference. The shorter these waves, the smaller may be objects which can be distinguished. A very fair idea of what happens may be obtained by comparing the process with the function of a so-called photo-mechanical screen, which consists of a glass plate divided into squares. In these the fineness of the details which can be reproduced increases with the smallness of the squares. The conclusion is that, in order to lower the limit of visibility as far as possible, we must employ light of as small a wave-length as we are able to operate with. It follows from this that blue light will resolve smaller elements than red light. But there are categories of light which are of much shorter wave-lengths than even the blue and violet rays. These are the *ultra-violet* rays, which fail to produce any visual effect on the retina of the eye but which powerfully affect the photographic plate. In this way the latter fixes not only what we are able to perceive with our senses but actually *supplements our organs of sense.*

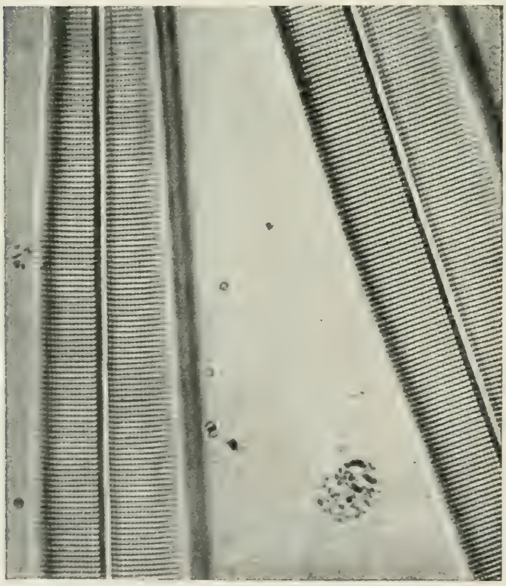


Fig. 33. Photo-microgram of *Amphipleura pellucida* taken with the "Monochromat".

These considerations have led Prof. Koehler to undertake very comprehensive investigations, as the result of which he has developed a very special system of photo-micrography by ultra-violet light. The objective used for this purpose is the so-called "Monochromat", which has been computed by Prof. M. v. ROHR, so as to embody a very high degree of spherical correction with respect to the one particular species of light which alone is transmitted through it. The limit of visibility, or resolution, has been pushed back very considerably in this way; in fact, the resolving power is practically

doubled as compared with ordinary light. This method has, in addition, another advantage. Many objects are exceedingly heterogeneous in their transmissive qualities relative to ultra-violet light, whereas in white light they can scarcely be differentiated. The effect is analogous to that obtained by artificial staining with dye stuffs, whilst at the same time the disadvantages of the staining process are obviated. Like the application of the X-rays, this method unravels unsuspected secrets of nature. It is therefore not surprising that within the short time that the method has been known it has already been applied in numerous and varied branches of research. We may instance the examination of the cells of the blood and of the tissues of the skin. Fig. 32 gives a view of this photo-micro-

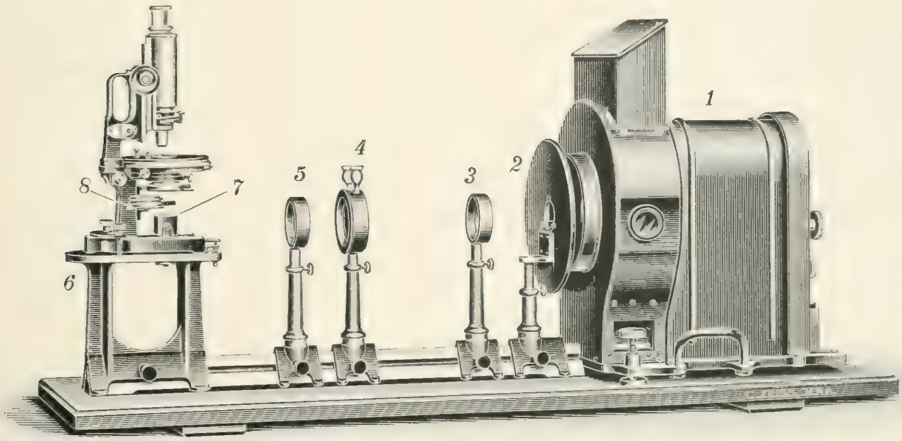


Fig. 34. Luminescence Microscope.

graphic apparatus, and fig. 33 shows a reproduction of a photo-micrograph of *Amphipleura pellucida*, originally magnified 1800 times, but shown magnified 2700 times in the reproduction.

In this connection it will be interesting to mention a new apparatus which likewise is designed for use with ultra-violet light. This apparatus is known as the Lehmann *UV-filter* lamp. This lamp is provided with a light-filter which has the property that it sifts out all light excepting the ultra-violet light corresponding to the spectral region ranging from 300 $\mu\mu$ to 400 $\mu\mu$. An important quality of the lamp is that the transmitted rays are of great purity, that is to say, they are not mixed with rays of other wave-lengths and they are of great intensity. This renders the apparatus

eminently well adapted for investigations in photo-luminescence (fluorescence and phosphorescence), a property which is imparted to most bodies after exposure to ultra-violet radiation. The UV-filter is particularly valuable for observing the luminescence during the actual exposure to radiation, since there are no vitiating visible rays in the energising light. Hence with this lamp luminescences of feeble intensity can be rendered visible, such as would be completely lost to vision if produced by exposure to impure ultra-violet light or to pure ultra-violet light of small intensity, such as may be obtained by the spectroscopic decomposition of light.

The luminescence analysis with the UV-filter lamp has already been applied with considerable success in various departments of the natural sciences, in physical and chemical research, mineralogy and physiology as well as in forensic medicine and has led to interesting discoveries. More recently this method has also been applied to microscopic objects, and in view of the success which has attended its application a *luminescence microscope* has been devised, as shown in fig. 34.

The Photographic Department.

When Abbe and Schott found themselves possessed of the new kinds of glass it naturally suggested itself to their minds to extend the consequences of the new achievements from the microscope to the other branches of practical optics. The suggestion ripened all the more readily into action since it was precisely at this time that Abbe had begun to clearly realise the necessity of rendering the growing establishment less dependent upon the vicissitudes which imperilled the existence of an undertaking concentrating upon a single object of manufacture. The result was that an attack was now launched upon photographic optics, and probably there could not have been a more propitious moment for this departure. It happened to be that very period when the photographer's art began to emerge from the confines of the professional photographer's studio to enter and permanently capture two new fields, upon which it had until then only strayed in a tentative mood. These new fields were the laboratory of the savant and the home of the amateur, whence it roamed from the precincts of the home into the wide world, there to gather pictorial records of things good, bad, and indifferent.

The first notable result of the new endeavours was a photographic lens computed by Dr. P. Rudolph, which visibly surpassed the then existing types of lenses in their performance. Abbe had already recognised

the importance of a system of optical correction in which spherical correction for relatively large apertures should go hand in hand with freedom from astigmatism and curvature of the image in the marginal zones of the lens. The problem was to produce a lens which would reproduce every point away from the axis as a point and not in the form of a blurred cross-like figure, and also to ensure that a plane object should appear as a plane in the resulting picture. It is along these lines that Abbe had furnished the incentive to the construction of a new photographic lens, which took the form of a triplet. In the process of working out this idea Dr. Rudolph arrived at the conclusion that a different type designed on the plan of a composite doublet would adduce more favourable conditions for the realisation of the principle.

In working out the formula of this type on the lines of the foundations prepared by Abbe, Rudolph gained an important advantage. Whereas formerly the computation of a photographic lens began with the elimination of colour defects, he was enabled by the new scheme to entirely ignore the colour correction at the outset and to endeavour at the conclusion to remove the chromatic defects by taking advantage of the greatly increased variety in the new list of optical glass. This procedure has eventually proved an exceedingly happy one.

The new lenses which resulted in this way in 1890 were first distinguished by the name *anastigmatic.* They embodied the principle of "inversely related refractive indices" in the front component and back component, inasmuch as the front lens consists of a crown glass with a lower refractive index than the flint glass, that is of glasses of the old series, and has allotted to it the duty of correcting the spherical aberration; while the back component consists of a crown glass with a high refractive index and a flint glass of a low refractive power, that is, partly, if not wholly, of glasses of the new series, and serving for bringing about the chromatic correction of the whole. Both components jointly correct, by reason of their mutual relations, the whole of the optical errors, including the colour dispersion and the curvature of the image.

The Anastigmatic Doublet, of which there were two forms, consisted of 2 + 2 lenses and 2 + 3 lenses, the latter type being the one shown in fig. 35. This first series was succeeded in 1893 by an anastigmatic single lens of three members and next, in 1894, by an anastigmatic single lens consisting of four members, which could be used independently and also as the components of a double objective (fig. 36) and for making up convertible sets. In 1900 the "Anastigmat" was given a legally protected name in order to prevent its being confused with imitations and lenses

of a similar type made in other establishments. The re-named "Protars", "Protar Lenses", "Double Protars" and "Convertible Protars" have become immensely popular with professional no less than with amateur photographers. So widely have their merits met with favour that within the last thirty years the Zeiss Works in conjunction with their licensees have supplied over half a million of anastigmats to all parts of the world.

In the course of further developments along the lines initiated by the anastigmatic principle several new types have been brought into existence, which have not failed to make their mark, the present wealth in photographic lenses notwithstanding. Their significance lies either in their special merits for a particular purpose or, on the other hand, in their all-round qualities, which are of the utmost importance to the amateur as he is thereby relieved of the necessity of equipping himself with a whole battery of more or less costly lenses. First among these we may briefly mention the "Unar"

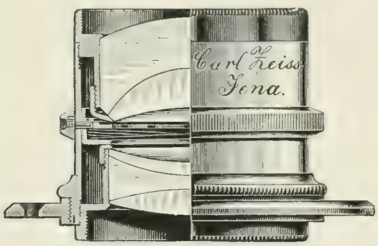


Fig. 35. Protar F/8 in standard mount with iris-diaphragm.

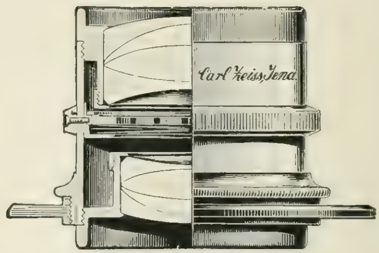


Fig. 36. Double Protar F/7 in standard mount.

of F/4·5 and F/6·3 originated in 1899. This anastigmat was made up of four lenses separated by air spaces and was therefore very inexpensive, but it has now been discontinued in favour of the Tessar lens, of which we shall speak presently.

The "Planar", introduced in 1897, is one of those lenses which serves special purposes. This lens was originally extensively used as a very rapid amateur and portrait lens. Under the name of "Microplanars F/4·5" its shorter focal lengths are unsurpassed for producing highly magnified or greatly minified pictures, whilst its longer foci are similarly without rivals as process lenses, both for autotype and line work (fig. 37).

All the lenses named so far can now only be regarded as secondary to the "modern lens" *par excellence,* which most concerns all who do not pursue specialised work and hence is the most valuable lens to the amateur. This is the *Tessar.* This lens embodies a simplification in construction as

compared with the Unar, which it surpasses in the matter of rapidity, sharpness of definition and flatness of field, whilst its field of view is slightly smaller. The first Tessars to be introduced from computations by Dr. Rudolph were Tessars of relative aperture F/6·3 for hand cameras, snapshots as well as colour photography, and Apochromatic Tessars of relative aperture F/10 for process work. Later, in 1907, on the initiative and from calculations by Dr. E. Wandersleb, two series were brought out having full relative apertures of F/3·5 and F/4·5.

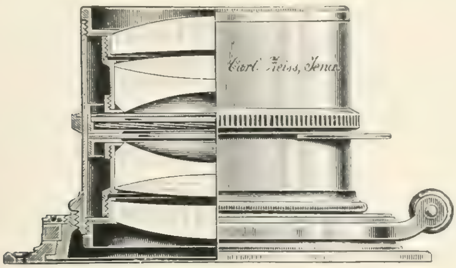


Fig. 37. Copying Planar Lens in standard mount with iris-diaphragm, Waterhouse diaphragm, and "revolving collar".

The shorter focal lengths of the Tessars are primarily employed on cinematograph cameras, whilst the longer foci are adapted for operating from aeroplanes and for like modern purposes requiring the very highest obtainable rapidity. The longer foci of the Tessar with a greatest rapidity of F/4·5 are mainly adapted for portraiture and for photography from aircraft. Their shorter foci have attained an enormous and ever growing popularity owing to their close approach to the ideal of a universal lens.

In figs. 38 and 39 will be seen reproduced a Tessar with a full aperture of F/4·5 in focussing "A" mount and in a "Compur" shutter, these being the two forms in which it is fitted to good hand cameras all over the world. It rapidly secured the lead in the world's markets, and it has not only maintained its position until this day but has further strengthened its supremacy from year to year. It is a significant sign of the superiority of this type of lens that for a prolonged period during the great world war the British War Office issued prominent advertisements in the daily papers in the endeavour to repurchase from private sources for use on

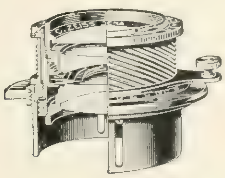


Fig. 38. Tessar F/4·5 in focussing "A" mount.

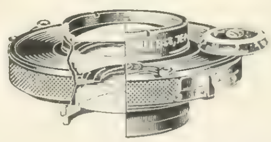


Fig. 39. Tessar F/4·5 in "Compur" shutter.

aeroplanes long-focus Zeiss Tessars of the F/4·5 series, great numbers of which had, of course, found their way into Great Britain and the Colonies before the outbreak of the war.

The introduction of the Tessar F/4·5 did not exhaust, however, the resources of the Zeiss Universal Anastigmats. There still followed improvements of the Protar Lens of four members and the Double Protar made up of them, the Protar F/9, and the Protar F/18, and in 1908 the Double Amatar made its appearance (fig. 40). The latter is a symmetrical combination, either half being of the type of the three-membered single lens of 1893 and capable of being used independently as a landscape lens of about double the focal length as compared with the double lens and having half its rapidity. From the Double Protar this new combination, the Double Amatar, differs mainly by its somewhat inferior rapidity and in that its components are made up of three lenses, in consequence of which it can be supplied at a lower price. It was found desirable to issue this lens as a supplementary accompaniment to the Tessar, since the existence of a large number of Zeiss hand cameras with double extension established a demand for a Zeiss lens of a moderate price. The Tessar F/6·3 did not satisfy this requirement since it is in the nature of the Tessar type that it may only be used as an inseparable doublet of an invariable focal length, at least until the introduction in 1914 of the Distar Lens created a new state of things.

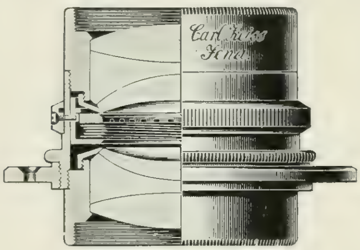


Fig. 40.
The Double Amatar in sunk mount.

Finally, in 1912, the computations of E. Wandersleb produced the *Triotar* F/6·3. This is a dissymmetrical objective consisting of three lenses separated by air spaces, and accordingly it belongs to a category of objectives which has been developed within the last ten years with great success, notably in England. Its range of uses on hand cameras is comparable to that of the Tessar F/6·3, but owing to its simpler make-up it is lower in price.

Now that we are speaking of universal lenses reference should be made to the *Distar Lenses*. These are simple meniscal lenses designed for attachment to the front of a photographic lens combination of a dissymmetrical type and having a fixed focal length, notably the Tessar F/4·5, F/6·3 and the Triotars F/6·3. They serve the purpose of increasing the focal length of the objective, to the front of which they are attached. The combination of a Tessar with a Distar Lens — Tessar + Distar Lens — has

very definite advantages over the single lenses of dissymmetrical or hemi-symmetrical doublets, in that there is less distortion, a greater freedom in the choice of the focal lengths, and that changes in the focal length can be made with lightning rapidity, besides which one is at liberty to extend one's equipment as and when required. In their formula these supplementary front lenses differ fundamentally from other lenses used in like manner. In fact, they embody the point-focal principle which has been applied with so much success in the so-called "Punktal" spectacle lenses as a means of obtaining perfect vision at very oblique angles. In consequence of the excellent definition which these lenses give when stopped down to a very small extent they have rapidly come into use and have extended the leading position of the Tessars by making them now also adapted for use on hand cameras with double extension.

Among the lenses for special purposes we may mention in the first place the Zeiss "Triplets" F/5 and F/7. These are made up of three lenses separated by air spaces, the middle one being a diverging lens, the two outer ones converging. During the war they served above all for every species of reconnaissance from air craft, where the larger field of view of the four-lens Tessar F/4·5 exceeded actual requirements. In these days they serve the peaceable purpose of making surveys from aeroplanes and airships as well as for portraiture.

There is another class of special photographic lenses which have always constituted a group to themselves. These are the so-called *telephotographic lenses* or, briefly *telephoto lenses*. It goes without saying that at the Zeiss Works this chapter in practical photographic optics was not neglected. In the category of telephoto lenses we must include all optical combinations in which a converging or positive front member is combined with a back member, usually of a diverging nature or negative, whereby the focal length becomes considerably longer than that of the requisite camera extension. For this reason they were formerly used extensively on hand cameras for taking photographs of distant objects, but now that they have been developed into fairly rapid combinations, they are also extensively used for portraiture and for recording the habits of small animals, that is, for that class of instantaneous photographs where the artist wishes to have large figures in the picture. Telephoto lenses were already produced at the Zeiss Works within the last decade of the past century. They consisted of a "telephoto tube mount" or "telephoto attachment", which joined the front member to the negative back member at variable distances, and at first the front member consisted of an independent telephoto lens made up of four cemented lenses. Later the rapid anastigmats, in particular

the Tessars F/6·3 and F/4·5, were made to form the front member, but telephoto objectives built up in this way could only in rare cases be employed to full advantage for instantaneous work. In 1905 the Works produced a new type of telephoto lens called *Magnars* (fig. 41), in which the freedom in the composition and relative position of the front and back members was sacrificed in exchange for important qualities, above all good defining power coupled with a rapidity which in many cases rendered the instrument available for instantaneous work. For special military requirements a telephoto objective was created in 1914, the rapidity of which was only F/50 but in which an exceptionally high power of definition was associated with the quality that a focal length of 10 feet required a camera extension of only about 5 feet. This rendered the camera portable to the extent that one man could carry it on his back over difficult ground, if need be. It could be set up anywhere and was available for taking photographs from very great distances. Quite recently the series

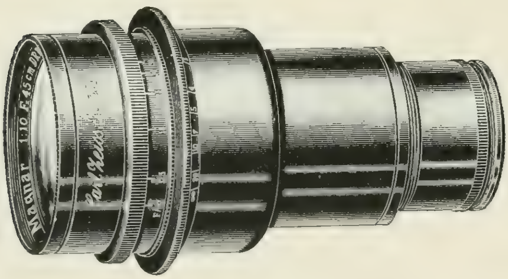


Fig. 41. The Magnar, half size.

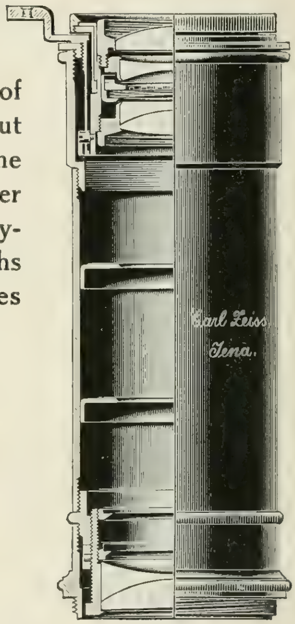


Fig. 42.
A telephoto combination.

of Zeiss telephoto lenses (fig. 42) has been brought to a certain stage of completion in the shape of the *Teletessar* F/6·3 computed by W. Merté. This objective has been primarily designed to serve the purposes of the amateur photographer and enables him, amongst other things, to use on his quarter-plate reflex camera with an extension of six inches a Teletessar F/6·3 of a focal length of ten inches as a companion lens to a Tessar F/5·4 having a focal length of six inches. The tele lens is fairly rapid and gives figures of nearly double the size as compared with the standard lens, naturally within a smaller compass of objects than are reproduced on a

quarter-plate by the short-focus lens. The Teletessar (fig. 43), like the Tessar, consists of two uncemented lenses in the front member and two cemented lenses in the back member. Its general make-up is similar in principle to that of the Tessar.

Special copying lenses for photomechanical processes are made on the lines of the Protars F/18 and Planars and, more especially and in increasing numbers, after the type of the Tessar.

It goes without saying that the Zeiss Works includes in its manufacturing operations such important items of the process worker's equipment as reversing mirrors and reversing prisms, as well as glass troughs with plane-parallel plates for the reception of filter fluids and similar optical auxiliaries. These auxiliaries need little, if any, serious contribution on the part of the mathematician, but all the greater are the demands which they make upon the most exacting care in all stages of their manufacture, which begins already with the examination and selection of the unworked glass plates in the laboratories. For it must not be overlooked that in the prisms the optical paths within the glass are of a length such as scarcely ever occurs in objectives of extreme diameters. The slightest defect in the homogeneity of the glass plate, like any slightest imperfection in the optical flatness of the surfaces, would inevitably disturb the wave surface and thereby impair the optical definition. In view of the great length of the optical path within the glass the presence of intervening striae and other flaws would give rise to heterogeneous conditions liable to disturb a pencil of rays which is required to form a sharp image of a point. Hence it follows that the glass has to be tested and selected with exceptionally critical care.

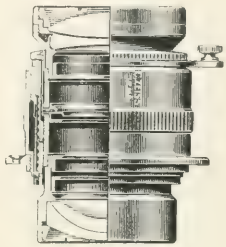


Fig. 43.
The Teletessar F/6·3.

Those who are more deeply interested in the theory and history of photographic optics and who happen to be able to read German may be referred to Prof. M. v. Rohr's book entitled "Theorie und Geschichte des photographischen Objektivs", which is a very exhaustive work of reference up to the year 1897, when it appeared.

Among the many optical auxiliaries which enter into the scope of photography we may briefly glance at a few which are made at the Zeiss Works. In 1905 the Jena Glass Works was successful in its efforts to produce a yellow glass coloured in the mass which is graded in its transparency with respect to the different colours of the spectrum in a manner which endowes it with the proper qualities for photographic work. The problem emanated from the Zeiss Works and consisted in so grading the

transmissive qualities of the glass that it should be perfectly transparent within the long-wave region of the spectrum up to the blue region, followed by a steep descent and almost complete opacity within the invisible short-wave region. As soon as the regular manufacture of the Jena yellow glass had been assured the Zeiss Works proceeded to bring out its yellow isochromatic glass filters for photographic purposes.

Then, a couple of years later, in 1907, followed the "Dukar" filters for colour photography on autochrome plates. In these plates the sensitive coating is on that side of the glass which faces away from the object to be photographed. The filters required for use with the autochrome plates are reddish yellow and demand definitely graded transmissive properties having two maxima. Now, in order to make allowance for the reversed position of the autochrome, as compared with the standard, plates and to render them straightway available for use on any camera and in the ordinary dark slide the required absorbing effect was associated in the Dukar filters with a very slight diverging effect, which caused the image formed by the objective to be transferred to the back of the plate. In devising this filter the object was to facilitate the application of the beautiful invention of the Lumière Brothers, which fulfilled an old dream of wishes and rendered it a simple matter, even from the amateur's point of view, to obtain photographs in natural colours. The name of "Dukar" was selected as a tribute to Ducos du Hauron, who was the first to draw attention to the potentialities of the colour screen, which has played such an important part in the development of natural colour photography and which was subsequently worked out by the Lumière Brothers.

When just before the end of the century Dr. Rudolph came to the conclusion that his work of introducing new objectives had reached its limit, for the time being, he set himself the task of evolving new camera models which should take full advantage of the superior qualities of the rapid anastigmatic lenses and which at the same time should be perfectly reliable in their action and remain so during several years of continual use. A company was established for the purpose in agreement with the Zeiss Works under the title of the "Palmos Camera Works", but soon after it liquidated and, so far as manufacture at Jena was concerned, the business passed into the hands of the Zeiss Works. In the autumn of 1910 Dr. Rudolph, after nearly twenty-five years of successful contribution to the greatness of the Zeiss Works, retired into private life.

The Palmos Cameras, which were exclusively hand cameras with metal bodies, were made until 1909, undergoing the-while further improvements. At this time several large German camera works, viz. the Hüttig Company

and the Wünsche Company in Dresden and Dr. Krügener at Frankfort on Main, as well as the Amateur Camera Department of the Zeiss Works, formed under the auspices of the latter, a large share company for the manufacture and sale of all kinds of photographic apparatus. Subsequently other firms joined the amalgamation. In promoting this amalgamation the Zeiss Works stood for a twofold aim. Primarily, it sought to place the camera industry in Germany on a sounder footing by lessening the disunion under which it was then suffering, and the next object was to abolish the competitive position of the Zeiss Works in relation to the large camera makers, who where also its largest lens buyers. The step so initiated had the desired effect in both respects. The Zeiss Works has discontinued the manufacture of cameras excepting only such as are designed for special scientific and military purposes. As regards the latter the Zeiss Works has played a significantly leading part in the photographic developments to which the war has given rise. During the first years of the war it developed and supplied a great proportion of all complete balloon and aeroplane cameras, in the latter part of the war only the very large cameras for focal lengths of 70 and 120 cm. (28 and 48 inches). On the other hand, until the end of the war it has supplied the *lenses* for all aeroplane and balloon cameras of the central powers, so that their reconnoitring "eyes" were almost exclusively produced at the Zeiss Works.

This is the place to mention a device which is made at the Zeiss Works for correctly viewing photographs. This is the *Verant*. It relates to a subject which is simple enough in principle but regarding which, even among enlightened people, there exist anything but clear notions.

Our ability to see natural objects in solid relief, not merely as flat pictures, we owe to the fact that we possess two eyes. To a certain extent the faculty of seeing objects in plastic relief is supplemented by experience and practice, so that even with only one eye we are partially able to realise the solidity of objects in space. This ability of seeing in relief is a psychical process, while vision with both eyes supplies the corresponding physical process. When we view a plain photograph there cannot be any question of a physical process by which the impression of solidity is produced; and so long as we use both eyes the impression cannot be obtained by psychical interpretation, for obviously the purely physical perception which is to be derived from a representation on a flat surface represses the psychical effort. Hence such a flat picture should rightly be viewed with *one* eye only. But even then the psychical process will not come into play unless the eye occupies that position relatively to the picture whence the photograph was originally taken. This explains why persons experienced in

viewing paintings frequently adopt the expedient of closing or, better still, covering up one eye and holding a short tube in front of the other, while standing a certain distance away from the picture. In the case of photographs taken with a certain focal length this correct manner of viewing may obviously be ensured by the use of a good combination of lenses which is free from distortion, such as the Verant lens, together with a stand which gives the picture and the lens combination their appropriate relative position.

While thus the Verant is a convenience, inasmuch as it saves one the trouble of searching out the proper stand-point whence a picture should be viewed, it becomes frequently a necessity with small amateur photographs, since in their case the focal length and hence the correct viewing distance are so short that it is impossible to correctly view the picture with the unaided eye. The effect of the Verant is nothing short of surprising when photographs are viewed through it which have one or the other of the common avoidable or unavoidable defects, such as the convergence of vertical lines, disproportion between the back ground and foreground, and so forth. In such cases the Verant restores the proper relations.

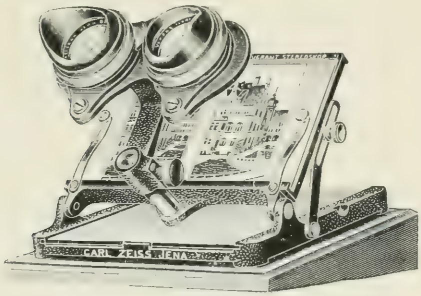


Fig. 44. The Verant Stereoscope.

The corresponding problem of the binocular viewing of stereoscopic pictures was solved by the *Double Verant.* The *Verant Stereoscope* (fig. 44) is a very convenient application of this principle, and can be used for viewing stereoscope pictures measuring $3^1/_2 \times 2^1/_2$ inches, which are now very largely met with. By its popularity it has for the time being superseded the Stereoverant despite the fact that the latter is optically the more strictly perfect instrument.

In connection with this summary survey of the photographic department we must not omit to mention a scientific and technical problem which has aroused the widest interest. We are referring to *photography in natural colours.* There are two entirely different principles between which we have to discriminate. The first is the so-called three-colour photography, which strives to derive all possible colour shades from three fundamental colours on the analogy of the prevalent theory of colour vision. The resulting process operates with three sensitive colour films which ultimately are combined by superimposed printing.

Two notable processes have been developed on this principle. One of these is the three-colour process in the narrower sense. It consists in three photographs being taken on three separate plates, either simultaneously or in immediate succession, and then bringing the three component pictures into coincidence either by optical projection through the appropriate colour-filters or by autotype superimposed printing with the appropriate colours. The other three-colour process is the three-colour screen method which was first rendered generally applicable by the invention and practical development of the autochrome plates and films by the Lumière Brothers. Thanks to the excellent results which have been obtained with it and the ease with which it can be applied this method is now widely practised. A small contribution to autochrome photography, apart from the great value of their rapid Tessars, has been made by the Zeiss Works by the introduction of the Dukar filters, which we have already mentioned. The reader will remember that these filters render cameras designed for ordinary standard plates at once available for use with autochrome plates.

Of less practical importance than the three-colour processes but all the more interesting from a theoretical point of view is the other principle of colour photography, which renders it possible to reproduce on a single plate all colours occurring in the original. This process is based upon the colour interference of the stationary waves which occurs within the sensitive layer. Lippmann in Paris and Neuhaus in Berlin were the first to work out successful processes for obtaining on this principle photographs in natural colours. At the Zeiss Works the problem was subsequently taken up and its development carried a little further. Incidentally new forms of apparatus were devised for taking, viewing, and projecting the colour photographs.

The Astro Section.

After many years of strenuous activity in other domains of practical optics, Abbe, astronomer that he was, was at last able to satisfy a long cherished wish and thus to apply the optical and mechanical resources of the establishment to the ideal purposes of astronomy.

The successes achieved with the new glass in other departments had indeed not failed to direct attention to the possibilities of its use in astronomical optics, but fundamental difficulties of no mean order stood in the way of their practical realisation. In the first place, it may not be generally known that the construction of astronomical instruments carries with it

enormous risks. To begin with, nothing can be achieved without a plant laid down on the grand scale. Such orders as may be placed are naturally far from numerous and derive their significance from the magnitude of the individual order, for the amount involved may run into several thousands of pounds sterling. Moreover, almost every order amounts to an individual task without precedent, which renders it no easy matter to arrive at a correct estimate of costs. Finally, when the Zeiss Works decided to enter the arena there were but few telescope makers, it is true, but these were firmly established in the public favour, so that a newcomer would have no prospects unless he felt himself strong enough to exceed the established standard of excellence.

Now, it so happened that at the time of which we are speaking the opportunity for surpassing the existing achievements was great enough, as in several respects it is so at the present time. This applies to the optical no less than to the mechanical side of the problem. This again implies the co-operation of competent technical specialists, and it will be readily appreciated that these are not easily procurable within such a restricted subject.

Optically there are three elements which enter into the construction of astronomical instruments. These are *lenses*, *mirrors* and *prisms*. Lenses occur in all eyepieces, and in the refracting telescopes they go to form the object glasses, or objectives to use the more modern term. Mirrors go to build up reflecting telescopes, which are among the oldest optical instruments. The prisms, finally, form an essential part of spectroscopic instruments.

As regards the construction of telescope *objectives* the Zeiss Works have the inestimable advantage of having in its immediate vicinity the Jena Glass Works, which recently has become identified with the optical establishment. Here the raw material from which the telescope lenses of modern giant dimensions are made and which formerly had to be obtained from France or England, is produced by processes which embody great improvements in several respects. Such giant lenses made at Jena from Jena glass have figured as objects of admiration at various exhibitions. We shall revert to the process by which these lenses are made in the chapter headed "A ramble through the workshops".

The first type of telescope objectives to be taken in hand were *ordinary telescope lenses* made of the customary kinds of silicate glass, but naturally the new and purer material and greatly improved modern methods enabled the Jena Works to produce much more perfect lenses and to proceed to very large dimensions.

Next follow the telescope objectives made up of *two members*, in which the new kinds of glass are employed to arrive at an incomparably higher stage of colour correction than existed before. This higher degree of correction removes not only the primary spectrum but almost completely eliminates the secondary spectrum. This type of objectives is accordingly described as *apochromatic*. Respecting the meaning of the term "apochromatic" the reader is referred to page 28.

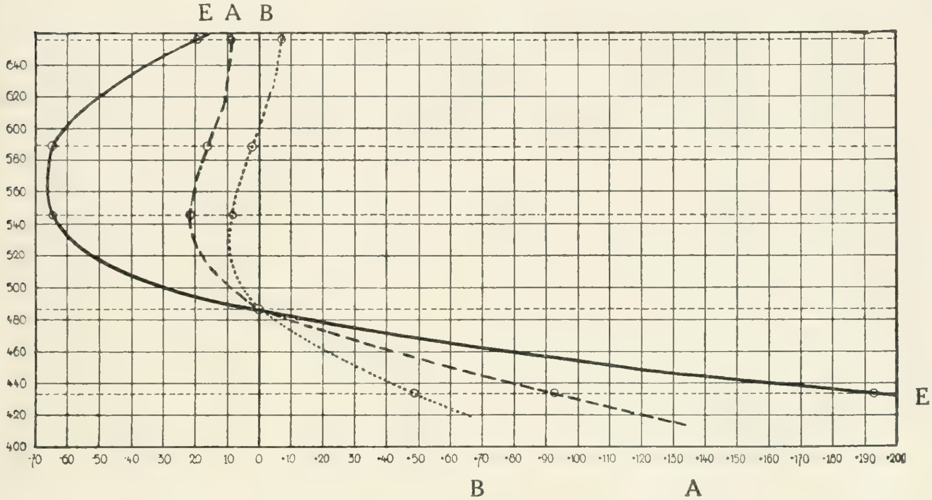


Fig. 45. The Colour Defects in objectives of the types *E*, *A*, and *B*.

The objectives classed under the letter *E* correspond to the old objectives made of the ordinary kinds of glass of the Fraunhofer series. The *A*-objectives are apochromatic objectives made up of two members, and the *B*-objectives are apochromatic objectives consisting of three members.

Still greater difficulties attach to the elimination of a further defect inherent in the old objectives, which is the variance in the amount of spherical aberration which exists with respect to the different colours. Complete elimination of this defect is quite unattainable, but it may be reduced to a minimum, and this can be done by the introduction of apochromatic telescope objectives made up of *three members*. As a matter of fact, the results so obtained have achieved a level in celestial observation which in the past would have seemed unattainable.

The diagram of fig. 45 gives in vertical ordinates the wave-lengths in terms of the millionth part of a millimetre of the various kinds of light which contribute to the formation of the image, whilst the abscissae,

measured from left to right, show the corresponding focal deviations in terms of the one-hundredth part of the focal length. From the curves shown in the diagram it will be seen that the older objectives of the E-type (represented by a full line) are corrected for two colours only and exhibit considerable deviations for all the other spectrum colours. The curves which are characteristic of the Jena apochromatic lenses, on the other hand, exhibit much smaller deviations from the vertical drawn through the zero point. The curve made up of dashes shows the amounts of aberration existing in the apochromatic A-type of two members, and it will be seen that they are only one half of those existing in the objectives of the E-type. The dotted curve represents the aberrations obtaining in the B-type of apochromatic objectives consisting of three members, and it will be seen that they amount to only one fourth of those existing in the E-type.

Eye observation, however, is only one side of practical astronomy. As in photo-micrography, so also in astronomy, the photographic plate will disclose in a great many cases what the eye is utterly unable to perceive. Often enough photography furnishes the only means of critical observation. Naturally, new endeavours to produce improved astro-photographic lenses were immensely aided by what had been accomplished in photographic optics; but considerable changes were needed in order to adapt the principles of photographic lenses for special application in astronomy and astro-physics. The efforts of the Zeiss Works have resulted in

Fig. 46. Astronomical Eyepieces with focal lengths ranging from 150 to 5 mm.

The long-focus eyepieces admit of the resources of telescope objectives with great focal lengths being utilised to their full extent in the matter of light-gathering power in the observation of faint and extensive objects, such as comets, nebulae, and such like, and also as regards the entire extent of their field of view. In large instruments the exit pupil may thereby be made as large as 8 mm., and the apparent field of view can be made to embrace an angle up to 70 degrees.

Fig. 47.
Two U.-V.-objectives composed of three members of a clear aperture of 360 mm. (14·17 inches) and a focal length of 4·5 metres (15 feet)

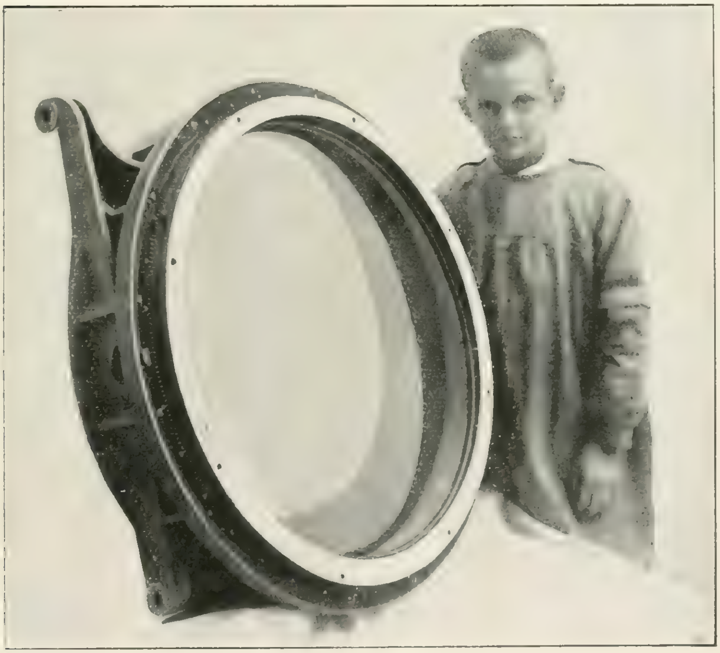


Fig. 48.
Objective Prism of the Cape Observatory, Diameter 640 mm. (25·2 inches). Refracting Angle 11°.

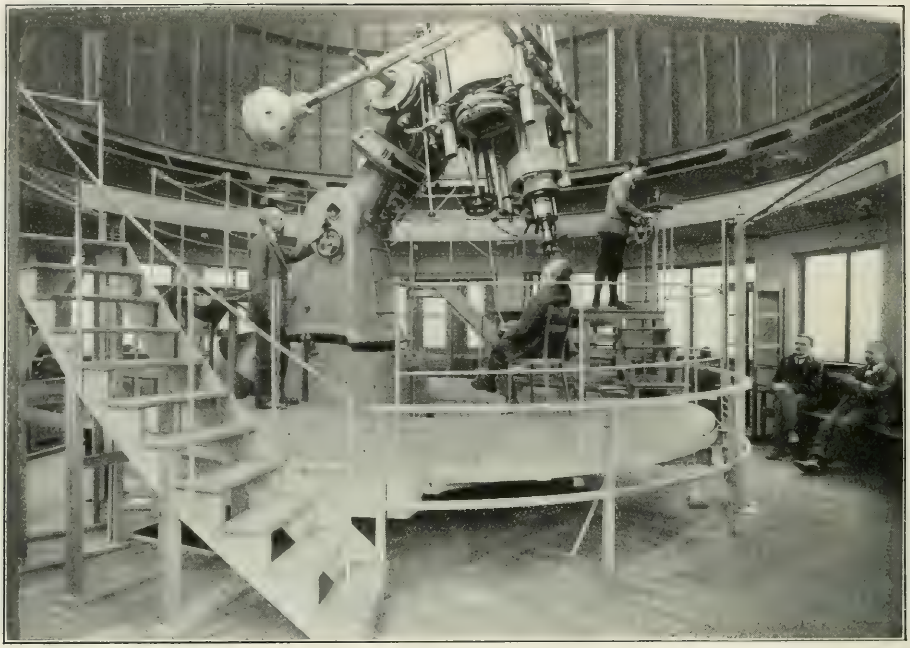


Fig. 49. Zeiss Works Observatory at Jena with experimental refractor and rising floor.

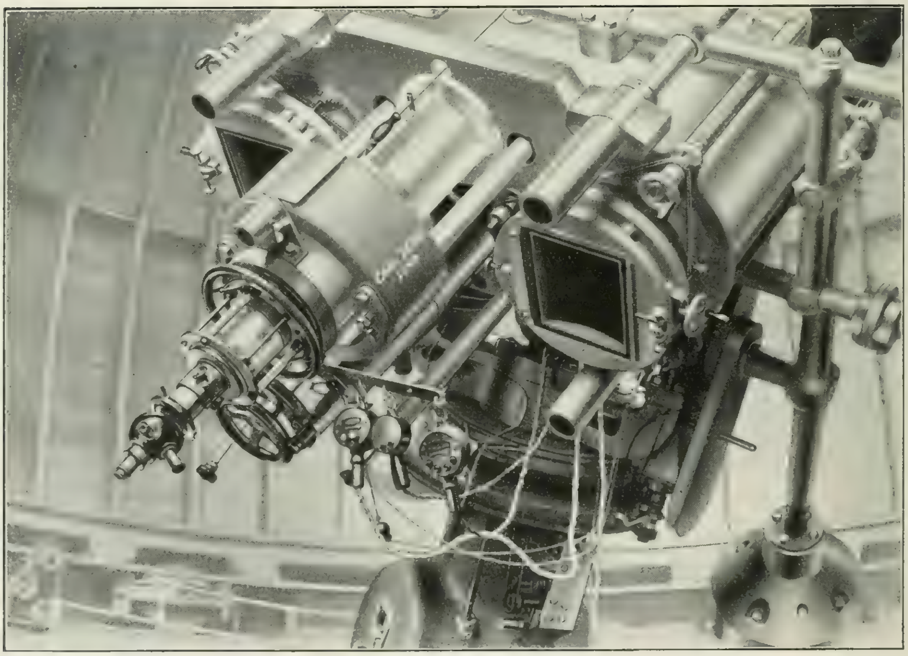


Fig. 50. Experimental Refractor at the Zeiss Works Observatory at Jena. Eye end of the leading telescope with triple revolving eyepiece changer. At the side of it electrical push for actuating the dome, the rising floor, and the electrically operated slow motions to the instrument. On either side the leading tube has an astro camera attached to it adapted for plate sizes of $12 \times 9^1/_2$ inches.

astro-photographic objectives composed of several lenses, notably the Astro-Tessars and Astro-Triplets, in addition to these the U. V. objectives for special ultra-violet work (fig. 47), for which the use of highly transmissive kinds of glass endowes them with superb qualities.

Let this suffice regarding the objectives. Our observations respecting the *mirrors*, or specula, will necessarily be brief. It may suffice to state that at Jena the application of extremely exacting methods of grinding and polishing has enabled the establishment to produce silvered glass

Fig. 51. The Observatory Dome on the Offices of the Zeiss Works.

specula which are almost entirely free from all optical defects of any consequence. They are equivalent to the best telescope objectives and even surpass them in their applicability to certain purposes. Amongst these are to be found specula which in point of size do not fall short of the giant lenses produced at the Zeiss Works.

The third and last element after the lenses and mirrors are the *prisms*, which are made with various refracting angles. Being intended for use in the body of telescopes, they are naturally shaped to fit cylindrical mounts. They serve for astro-physical work, that is to say, for viewing and taking

permanent records of star spectra. In fig. 48 will be seen an objective prism of that kind. In conclusion we shall briefly refer to the great variety of eyepieces made for use with the lenses and specula, as indicated in fig. 46.

The completed optical instrument is tested first in the laboratories and finally by training it upon a celestial object. For this purpose the observatory of the Zeiss Works (fig. 49) is provided with a special trial instrument (fig. 50). This is housed under a dome of a diameter of 29 1/2 feet, which has been erected on the top of the office building of the establishment (fig. 51). Incidentally it gives visitors to the establishment an opportunity of making observations with a large instrument.

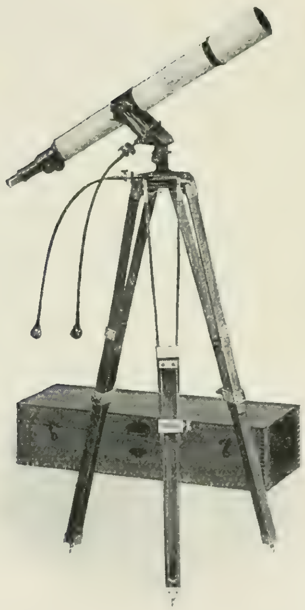


Fig. 52.
Telescope in altazimuth mount with slow motions.
60 mm. (2·36 in.) clear diameter and focal length 0·85 metre (33 1/2 feet).

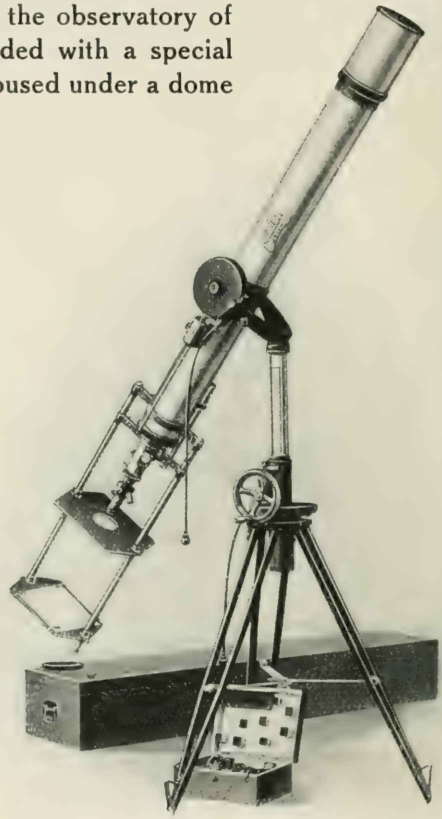


Fig. 53. Telescope in altazimuth mount with slow motions controlled by a worm gear, elevating gear, revolving changer for three eyepieces, and solar projection screen. Clear diameter of objective: 130 mm. (5·12 in.).
Focal length: 2 metres (6 1/2 feet).

When astronomical optics entered into the activities of the Jena Works, the whole of the mechanical part of telescope making and astro construction was taken up at the same time, as it was fully realised that it is

Fig. 54.
Equatorially mounted telescope with objective of 80 mm. (3·15 inches) clear diameter.

desirable for the maker no less than the destined user that telescope and observatory and all their appurtenances should be regarded as a well

thought-out whole. It would by far exceed our purpose were we to attempt to describe the details of the telescope mountings in their exceedingly varied forms. It must suffice us to know that they are broadly distinguished as *altazimuth* and *equatorial mounts,* either of which has its peculiar advantages.

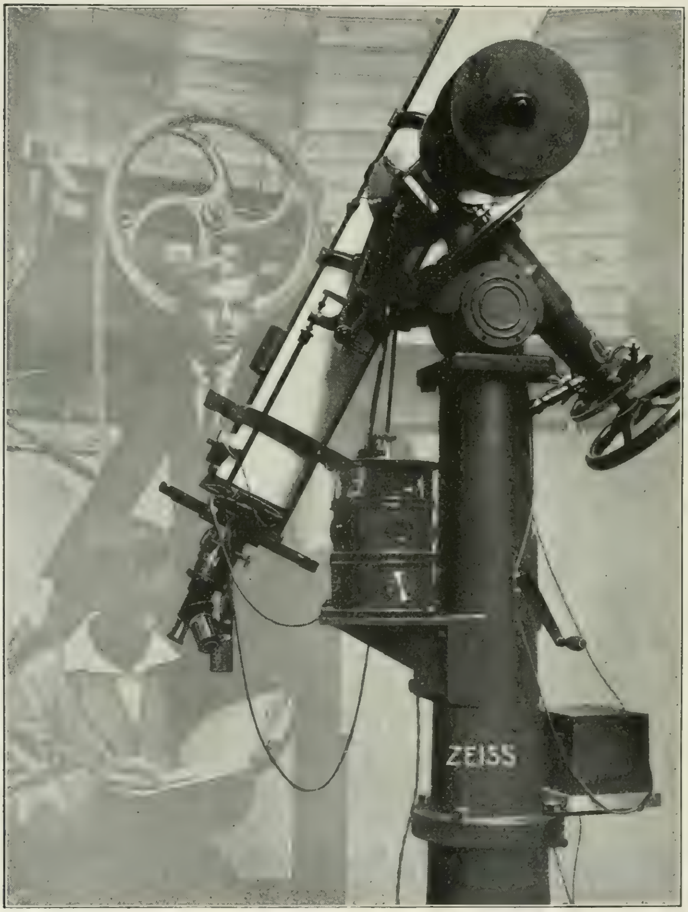


Fig. 55. 130-mm. (5-inch.) Refractor at the Observatory of the "Gymnasium" (Public College) at Burgdorf (Switzerland).

The telescopes themselves, of which there are numerous designs and sizes, are adapted for the requirements of professional and amateur astronomers as well as for recreation in general, and in the case of the smaller instruments the astronomical equipment is naturally supplemented so as

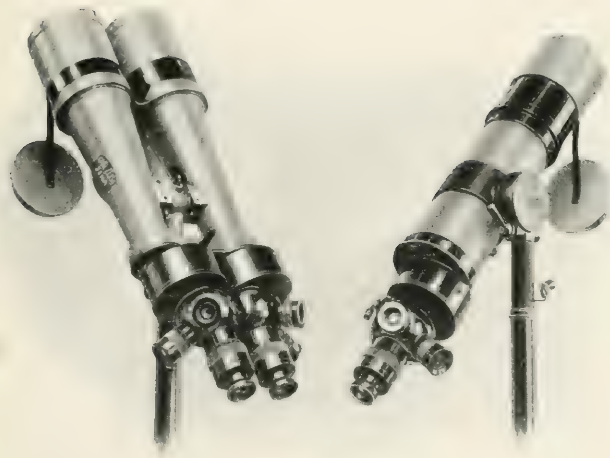


Fig. 56. Short-focus View Telescopes magnifying 12, 20, and 40 times and having objectives of a clear diameter of 80 mm. (3·15 inches).

to render them available for terrestrial observation, i. e. for seeing distant objects on land or at sea. These supplements include above all certain modifications, in particular the indispensable devices whereby objects are seen in their natural erect and unreversed position, since the astronomical telescope naturally furnishes inverted and reversed images. For both modes of observation the telescopes may be furnished with eyepieces giving a wide range of magnifications, and, in addition to telescopes adapted for observation with one eye only, there are others of a binocular type. Some of the latter, again simply admit of the use of both eyes in the ordinary way, others, however, greatly enhance the natural impression by which a landscape as seen through the telescope stands out in

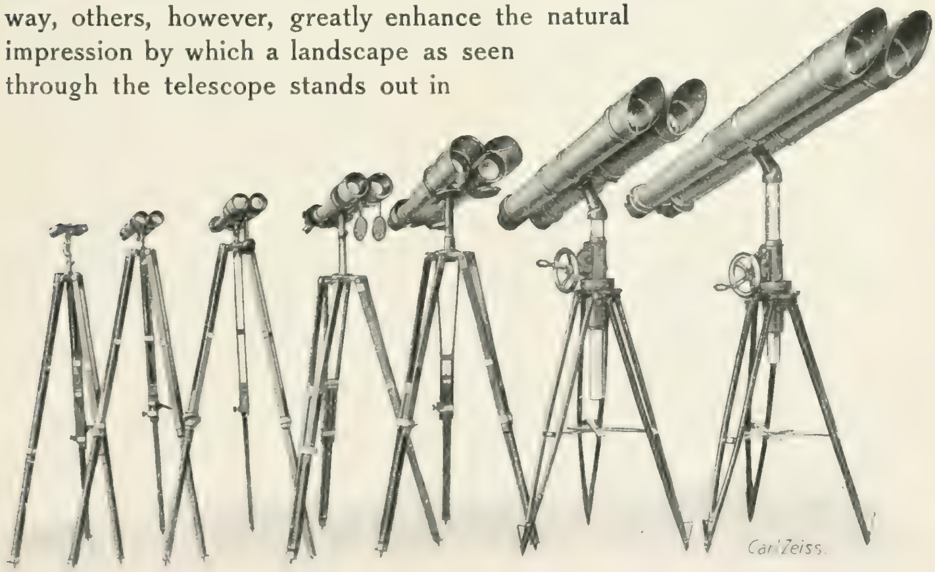


Fig. 57. Double Telescopes.

Fig. 58. 130-mm. (5 1/4-inch.) View Telescope set up on the Riffelalp above Zermatt.

solid relief. The application of this enhanced stereoscopic relief has brought about such far reaching results that we shall revert to it more fully in our next section.

Space compels us to rest content with a few sketchy references and to let the illustrations rather than the text indicate the wide range of large and small telescopes made at the Jena Works. The amateur may there find instruments which satisfy every requirement in the matter of power, performance, and convenience to meet his ends. These include *travelling telescopes* (figs. 52 and 53), which enable him to make astronomical observations wherever he happens to be staying; likewise larger *stationary telescopes*, some of these equipped with a triple revolving eyepiece changer as well as a *finder*, which give him an opportunity of studying more deeply the secrets of the starry heavens. Thus fig. 54 exhibits a comparatively simple, fig. 55 a rather more complicated telescope.

Telescopes of this kind, though primarily designed for astronomical use, are provided with an image erecting prism attachment, which renders them available for viewing terrestrial objects. Telescopes of this kind are shown in fig. 56. The same naturally applies to the view telescopes proper, a large number of which occur already at the most famous view points in Germany, Austria, Switzerland and other countries. In many cases these telescopes are fitted with automatic coin-in-the-slot devices, and their owners have been known to recover the original cost by the accumulated small charges made within the first or second season. In fig. 58 will be seen one of these instruments. These view telescopes have clear apertures ranging from 24 mm. (1 inch) to 130 mm. ($5^{1}/_{4}$ inches) and magnifications from 6 to 116.

This brings us to the purely scientific instruments of this class. One of the main problems which this section has proposed itself and which it has succeeded in solving in a truly ingenious manner was to unite in one instrument such seemingly irreconcilable qualities as perfect stability and convenient control of all movements with complete freedom of motion and a correct balance of all parts and attachments. Thus, to instance only one interesting feature in some of the new designs, the point of intersection of the axes of rotation has been brought so near the position of the observer's eye that the most extensive excursions of the telescope across the celestial hemisphere necessitates very small changes in the observer's position, whereas in the usual designs the observer is often compelled to follow the eyepiece through considerable and fatiguing distances (see figs. 59 to 61).

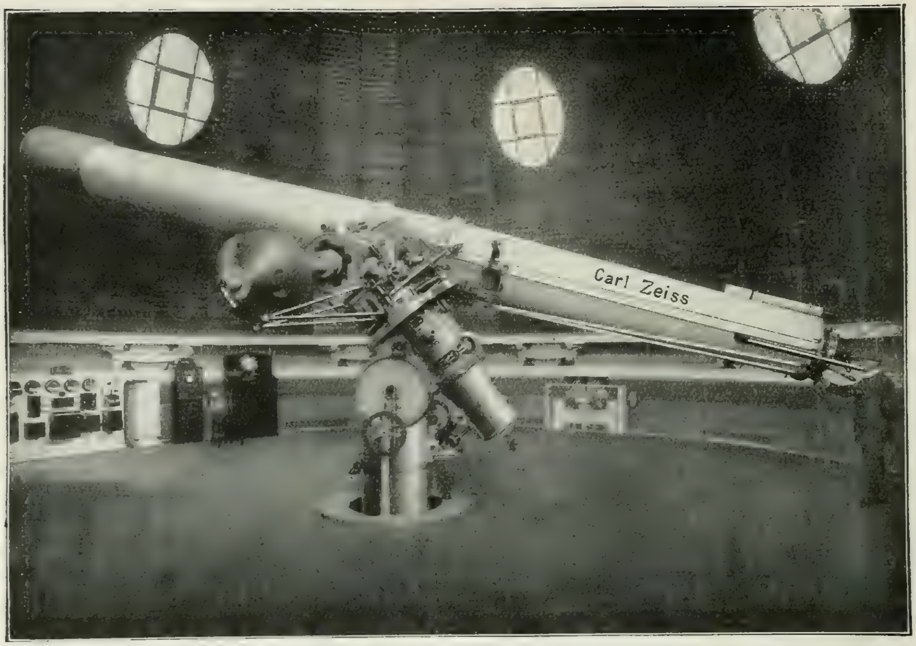


Fig. 59. 650 mm. ($25^{1}/_{2}$ inch.) Refractor of 10·5 metre ($34^{1}/_{2}$ inch.) focus with dome 14·5 metres (48 feet) in diameter and rising platform of the Observatory at Berlin-Babelsberg.

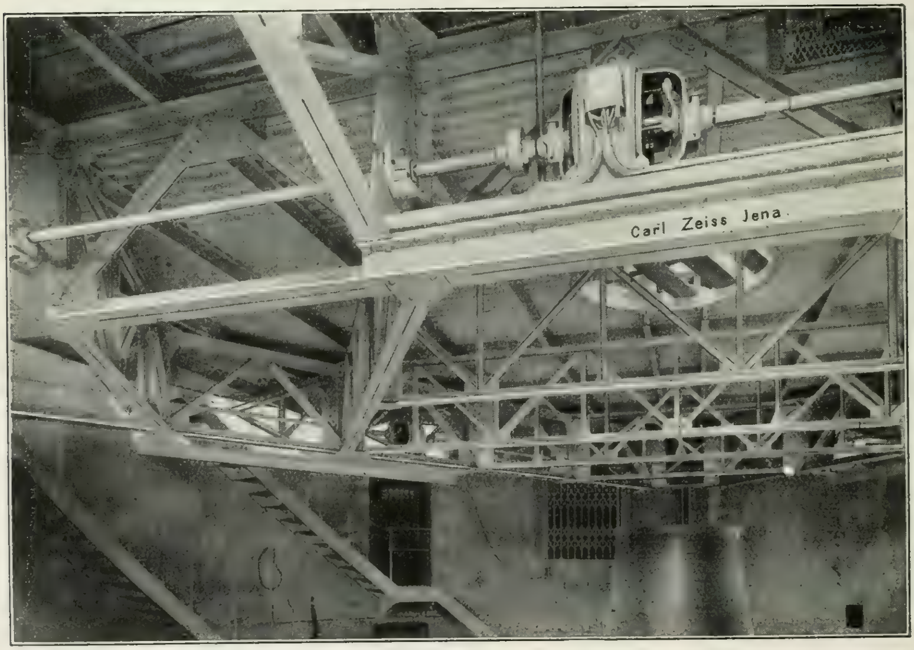


Fig. 60. Rising Platform to the 650 mm. ($25^{1}/_{2}$ inch.) Refractor as it appears from below.

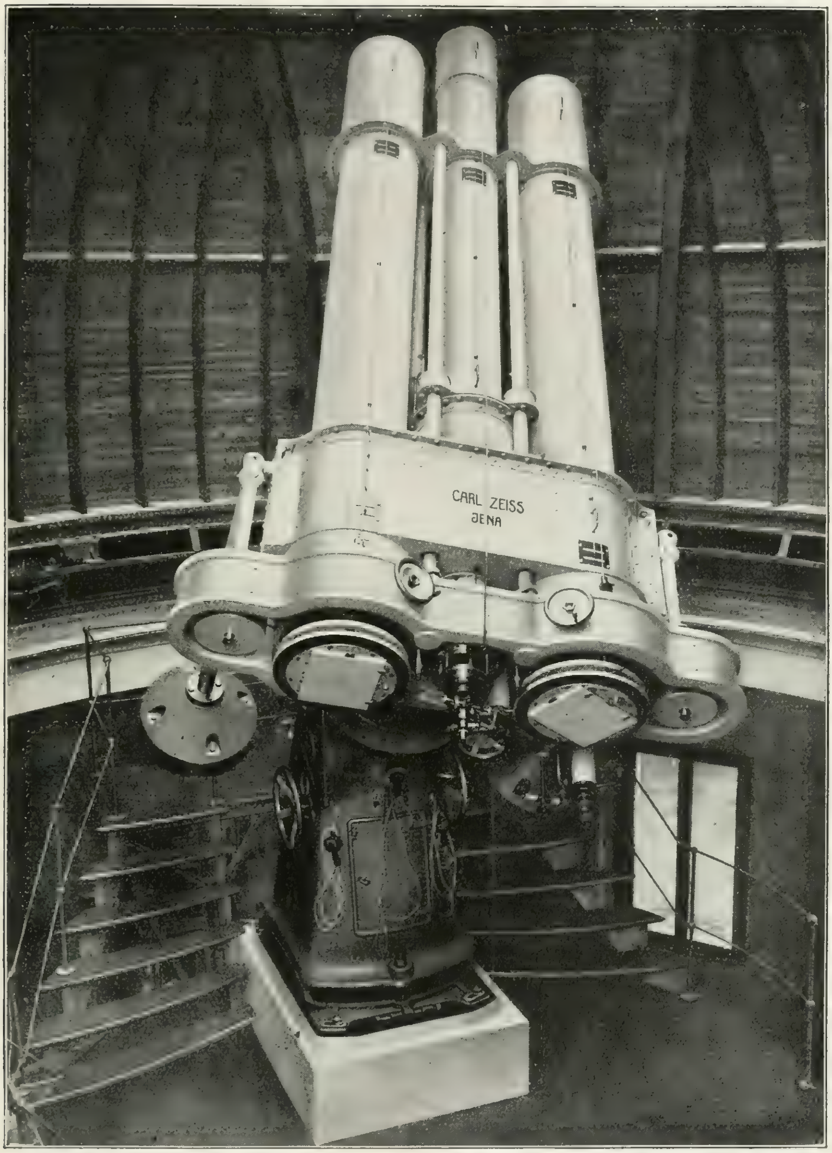


Fig. 61. Triple photographic refractor of the Observatory at Neuchâtel (Switzerland). The visual leading telescope has an objective 300 mm. (11¾ inch.) in diameter and of a focal length of 5 metres (16½ feet), two astrophotographic tubes with U.-V. triplets of a diameter of 360 mm. (14¼ inch.) and focal length of 4·5 metres (14¾ feet).

If the reader will cast a glance upon the pictures of the combined instruments shown in figs. 61 and 63 he will see that the former standard type of equatorial mount is resolved into two distinct systems, viz. an outer carrying system and an inner guide system. The telescope consists of an

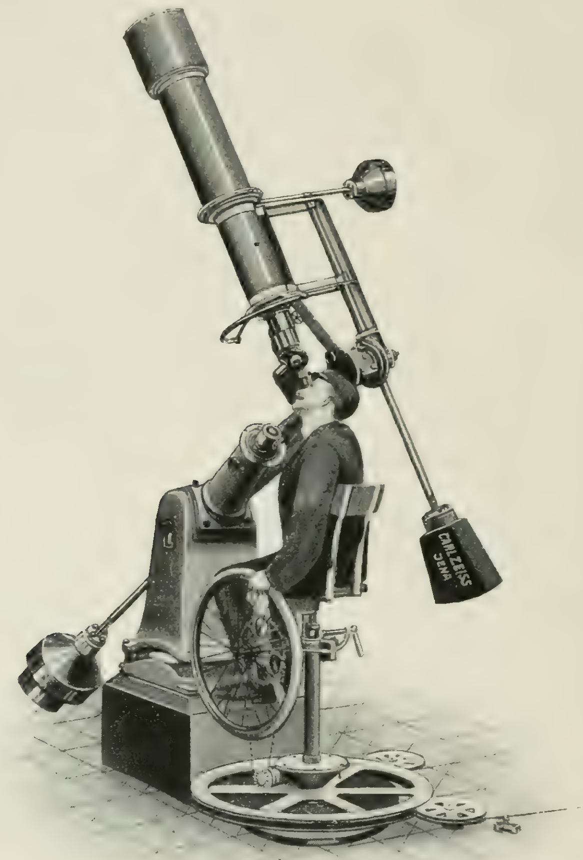


Fig. 62. 200 mm. (7·8 inch.) Comet Finder of the Observatory of La Plata. Diameter of the objective 200 mm. (7·8 inch.). Focal length 1·2 metre (47 1/4 inch.).

outer carrying tube which neutralises any tendency of the telescope to bend by the application of balance weights at the eye end and an inner guide tube which carries the objective and the eyepiece. The telescope is made to follow the apparent motion of the star in a very exact manner by an automatic electrical gravity clock with governor and electrical seconds

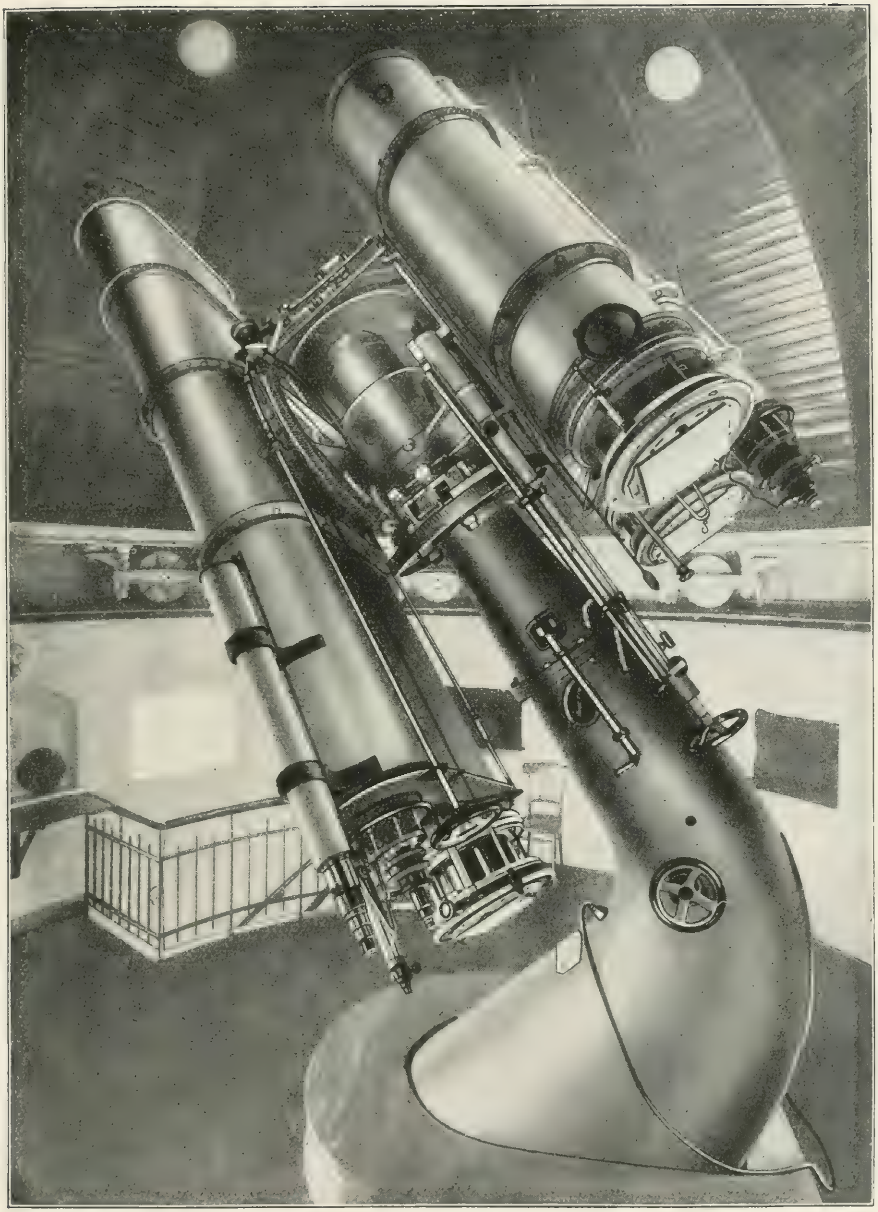


Fig. 63. 340 mm. (13·4 inch.) Lippert Astrograph of the Hamburg Observatory at Bergedorf. U.-V. Triplet, with a clear diameter of 340 mm. (13·4 inch.), focal length 3·4 metres (11 feet) Leading tube with 230 mm. (9 inch.) objective, focal length 3·4 metres (11 feet). Two short-focus astrophotographic objectives, diameter of objectives 300 mm. (11·8 inch.), focal length 1·5 metres (59 inch). Leading tube, diameter of objective 200 mm. (8 inch.), focal length 2·7 metres ($8^{3}/_{4}$ feet).

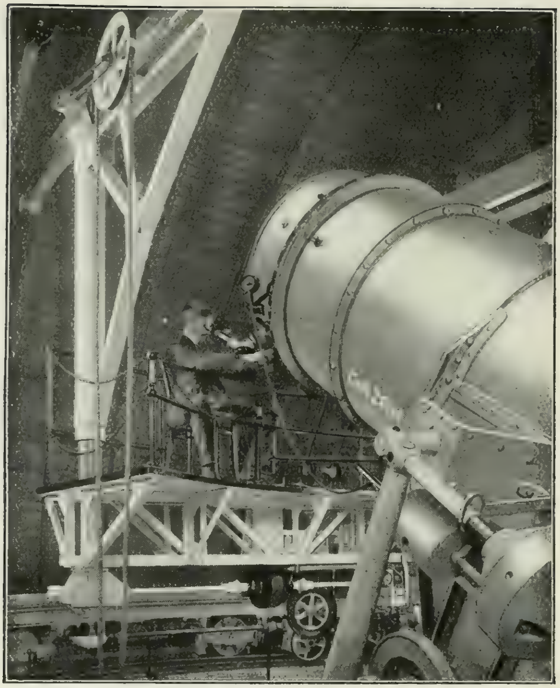


Fig. 64. 1 metre (40 inch.) Reflector of the Hamburg Observatory at Bergedorf. Showing the eye end of the reflector tube and the movable platform.

control. The motion is automatic, so that the observer is not called upon to trouble about the driving mechanism. The type of refractor mounting here indicated has particular advantages when the refractor mount includes astrophotographic telescopes. In this case the system of balancing does away, as it is essential that it should do, with any flexion of the tubes relatively to each other.

Telescopes of great light-gathering power and of medium size, such as are employed for searching the heavens for nebulae, comets and other faint objects, so-called comet finders, are so mounted that the observer's eye may be situated at the point of intersection of the axes of rotation and so that the observer may operate the motion of the dome by means of a hand wheel at the side of his observation stool (fig. 62).

Large astronomical instruments afford very striking evidence of individual requirements. Thus in the case of the Lippert astrograph of the Hamburg Observatory at Bergedorf shown in fig. 63 a single mount has been designed to carry no less than five telescopes, which is a striking and original method of exhausting the resources of the equatorial motion.

Fig. 65
Binocular Eyepiece attached to an astronomical telescope.

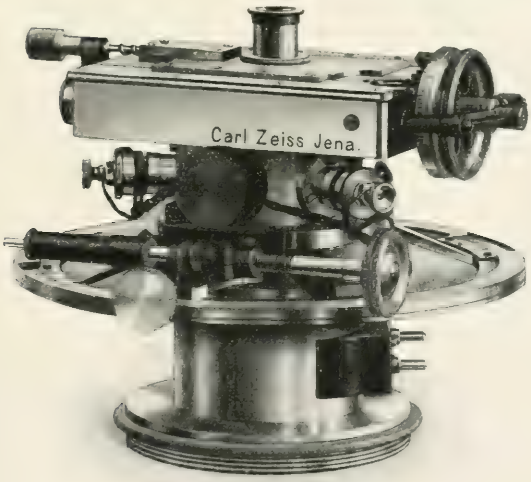


Fig. 66.
Position Filar Micrometer, small model.

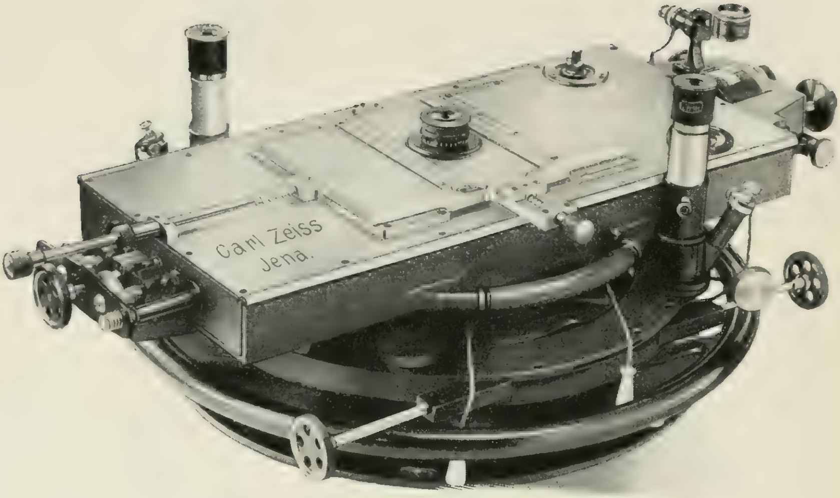


Fig. 67. Position Filar Micrometer, large model.

Fig. 64 furnishes an example of a large modern reflecting telescope.

Of the many accessory instruments which form the equipment of a large astronomical instrument it must suffice to select a very few examples. Fig. 65 shows us a binocular eyepiece, fig. 66 a small and fig. 67 a large position filar micrometer, which serves to measure the relative angular distance of comets and small planets from neighbouring fixed stars, the separation and orientation of double stars, and many other celestial quantities. Another prominent accessory is the prominence spectroscope, which has an exceptionally great dispersion, whilst its handy form is maintained by the use of reflecting prisms. Fig. 68 gives us an idea of the arrangement of the solar and lunar camera with positive enlarging combination, yellow screens, instantaneous shutter and orthochromatic plates. Fig. 69 shows the general appearance of large astro-spectrographs, which attach to the dark slide end of large photographic telescopes. They serve for photographing the spectra of faintly luminous celestial objects, such as fixed stars, nebulae, and such like. The optical equipment of these astro-spectrographs comprises prisms and lenses made of material which is particularly transparent to photographic rays, such as quartz, fluorite, and uviol glass; and there are special devices whereby the optical parts are protected from changes of temperature, which is essential as the exposures frequently continue for hours. Special thermo-couples and thermopiles have been devised for controlling the temperature, and numerous other appliances which form part of the equipment of an astronomical observatory.

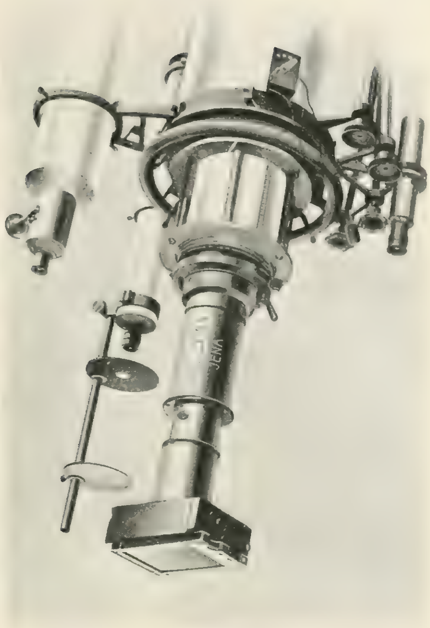


Fig 68. Solar and Lunar Camera Attachment to the telescope.

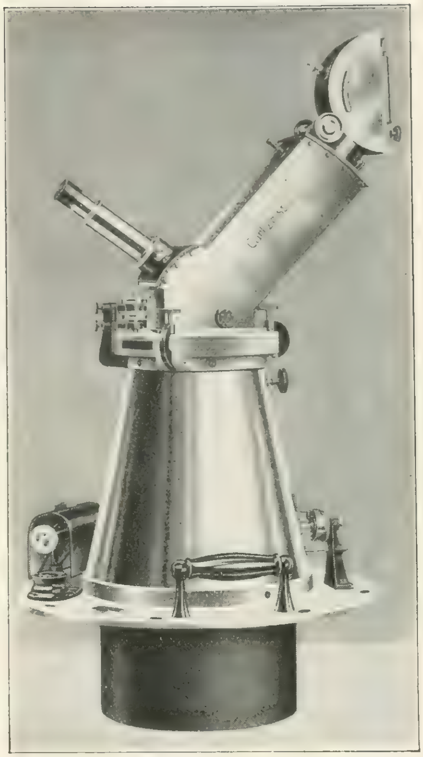


Fig. 69. Single-prism U.-V. Spectrograph.

In this connection it will be interesting to say a few words about the thermopile, which is not only an important auxiliary in telescopic observation but also is greatly used independently for measuring through the agency of electrical currents the intensity of radiated heat. It consists of a combination of two metals with a soldered junction. At the Zeiss Works this instrument is made in new special forms, which have proved most successful. Fig. 70 shows one of these new arrangements. In another, combined, form of the instrument the radiation receiver is associated with a vacuum thermo-couple and a parabolic mirror.

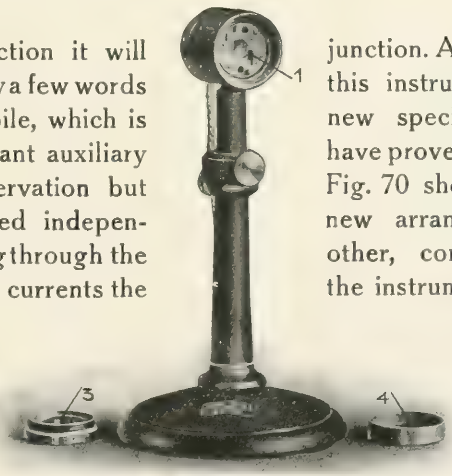


Fig. 70. The Thermopile.

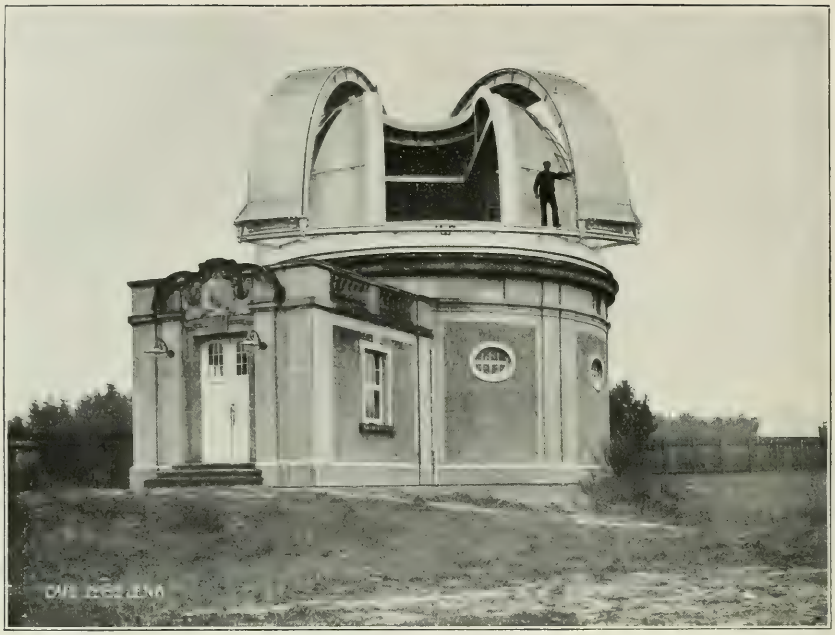


Fig. 71. The Hamburg Observatory, showing the 9·5 metre (31 feet) dome over the 100 cm. (40 inch.) reflecting telescope.

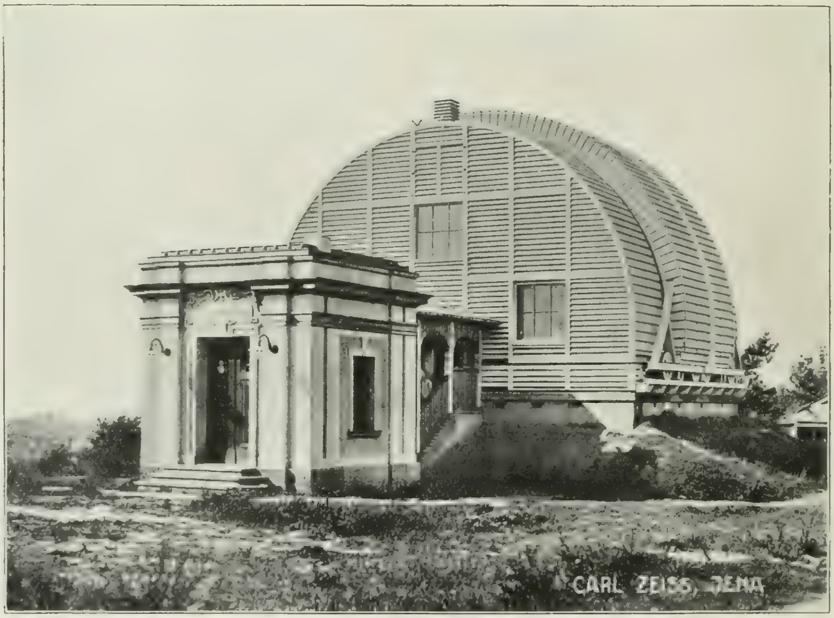


Fig. 72. The Hamburg Observatory at Bergedorf. Arched roof over the large meridian circle.

Fig. 73. Kvistaberg's Observatory. Dome of an inside diameter of 3·5 metres (11 1/2 feet).

We now come to the last, and in one sense most extensive, item in the astronomical section. For this section undertakes the construction of the *observatories* themselves, wherein the astronomical instruments are safely housed and which are designed and equipped for carrying out observations without mechanical impediments. The domes and other overhead coverings require to be adapted to suit the special conditions which arise in each given case. We shall not be far wrong in instancing as one of the latest observatories that of the State of Hamburg at Bergedorf, which is fully furnished with an entirely modern equipment. It consists of a number of distinct buildings, two of which, the dome for the large reflecting telescope (fig. 71) and the arched roof of the large meridian circle (fig. 72) are shown in our illustrations. Fig. 73 shows a small observatory on an unobstructed hill. In this case, as in most modern observatories

Fig. 74. Observatory of the "Urania" at Zurich. Wooden dome 8·4 metres (27 1/2 feet) in diameter, covered with copper.

erected for purely scientific purposes, a carefully selected spot in the country provides the requisite site, but when the primary object of an observatory is to develop in the popular mind a desire for cosmic knowledge, the observatory must necessarily remain within the confines of a town, as in the case of the Zurich "Urania". The only way to mitigate

Fig. 75. Observatory of the Public School at Erfurt, with dome 4·9 metres (16 feet) in diameter.

local disadvantages is then to build above the vapour and dust of the town and to erect the observatory on a towerlike structure, as can be seen in fig. 74. Similar conditions arise in the case of school observatories, though in their case the dimensions do not exceed certain modest limits. An instance of this kind is furnished by the State School at Erfurt (fig. 75). In fig. 76 will be seen an example of a private observatory. These are all

cases of the kind where it is often far from easy to reconcile the wishes of the prospective owner with the purely astronomical exigencies of the case and at the same time bring the whole into architectural harmony with its surroundings.

It is, of course, imperative that observatory instruments destined for scientific investigations should be protected from vibrations and other external influences, noises, and such like. Modern observatories are for this reason mostly built on the pavillion plan, each instrument being accommodated within its own ground floor building.

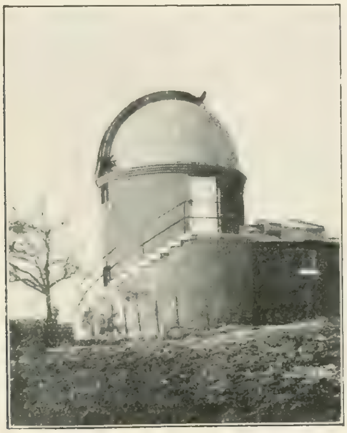


Fig. 76. Private Observatory of Dr. Rosenberg, at Tübingen.
Wooden dome 4·3 metres (14 feet) in diameter, covered with ruberoid.

Fig. 77.

Above: The Planetarium within a hemispherically domed projection rotunda.

On the left: The apparatus itself.

The apparatus comprises a hemispherical body upon the surface of which there are seventy-two small optical lanterns for projecting upon the hemispherical surface the fixed stars, the milky way and the names of the constellations, and a cylindrical body, shown on the left in the figure, which contains the projection lanterns and the motion mechanisms for the sun, the moon, and the planets.

The Zeiss Planetarium.

In the course of our description of astronomical instruments in the preceding pages we have become aware of the existence of a wide range of instruments and devices for the study of the processes which occur in the starry heavens. Though these instruments are to be found in all parts of the globe, yet it is only a vanishingly small number of professional and amateur astronomers who have the handling of them. The vast majority of humanity must be content to gaze upon the denizens of the heavens in helpless wonder and mystification. Indeed, a moderately true interpretation of what can be seen with the naked eye is given to very few, and that many treat the heavenly wonders with profound indifference is not altogether their fault.

Here again the Zeiss Works has come to the rescue of those who would if they could. Inventive imagination and scientific resources of no mean degree have cooperated to create a new order of astronomical apparatus in the shape of the Zeiss Planetarium. This is an instrument which serves, not for observing the heavenly bodies and their movements, but which imitates in natural exactness on an artificial sky the secular processes which present themselves to the unaided eye on the natural sky.

The apparatus may be regarded as an assemblage of eighty-two projection lanterns by means of which all fixed stars which can be seen with the unaided eye, up to the sixth magnitude, as well as the sun, moon, and the planets Mercury, Venus, Mars, Jupiter, and Saturn are shown in motion on the inner surface of a hemispherical projection screen. All these projection lanterns are controlled by ingenious electrically operated mechanisms and the resulting appearances and movements are such that the spectators, hundreds of whom may be accommodated under this artificial sky, will have the impression that they are contemplating Nature's great heavens. Whilst the natural movements of the heavenly bodies are so slow from the human aspect that the mind behind the eye is unable to interpret them in terms of coherently related pictures, the mechanisms which control the movements across the artificial sky can be accelerated to such an extent that the spectators may see the processes which occupy days and years condensed into the span of a few minutes. They are enabled to study and understand these processes, unhindered by the vicissitudes which stand in the way of astronomical observation, and the mathematical mysteries of the planetary movements, those of the sun and moon, and the changes of the seasons are reduced to intelligibly continuous and readily followed motions. It is not surprising that almost every spectator who for the first

time sees the stars shine forth on this sky on earth unconsciously proclaims his delight and is stirred by a sense of revelation. It is not surprising, but it is also a lamentable proof of the veil of ignorance that curtains off the natural heavens from the mental eye of human beings. And when we remember that millions of people in large towns hardly ever see the starry heavens at all, we cannot over-estimate the ethical and educational value of this wonderful interpreter of Nature's mighty rule in space.

Unfortunately, the Planetarium demands for its accommodation and the exercise of its powers a large hemispherical projection rotunda, and experi-

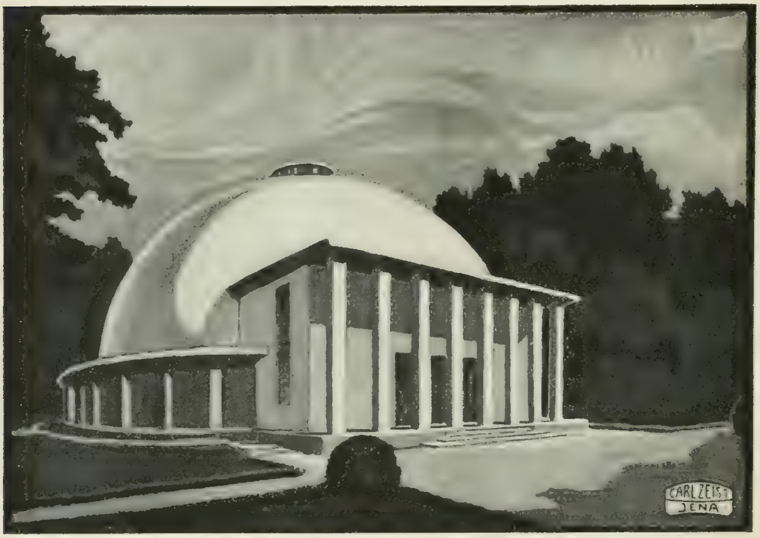


Fig. 78. The Planetarium at Jena.
Diameter of dome 82 feet. Building designed by the architects Messrs. Schreiter and Schlag, of Jena, and executed by Messrs. Dyckerhoff & Widmann, of Biebrich o/Rh.

ments have shown that in order to complete the illusion of an infinite celestial space the rotunda should have a diameter of about 80 feet. A hemisphere of this size is moreover desirable in order that the rotunda may accommodate a large number of spectators, say, six-hundred.

Now, a rotunda with a dome 80 feet in diameter is in itself a structure involving architectural problems, and it must not be overlooked that very few of the largest observatories boast such large domes.

To meet the architectural problem the engineers of the Zeiss Works have evolved a new and ingenious type of dome, which reduces the requisite material and consequently the cost of the building to a minimum. A lattice truss of slender bars has been computed which requires only a few centimetres of concrete, applied by spraying, in order to form the finished hemisphere.

This dome structure, which has been evolved from first principles, has proved eminently well adapted for the construction of large factory sheds, exhibition halls, etc., thanks to the small amount of material used and the consequent economy in the building cost. Halls with domed roofs up to 130 feet in diameter have already been constructed on this new principle with great success. A good idea of the economy of material realised by this system can be formed if one realises that a dome 130 feet in diameter, if reduced to the size of a similarly shaped segment of a hen's egg is thinner in proportion than the latter's shell.

Here, then, we have a case where technical ingenuity has transcended in giant dimensions the structural achievements of nature. It has actually beaten Nature in her economical department. The spectator within a Zeiss Planetarium therefore has occasion to admire under the giant egg-shell which forms the artificial firmament two masterpieces of technical art joined to fulfil a new mission in the service of science and the elevation of the masses.

The Terrestrial Telescope Department.

In passing from astronomical telescopes to those designed for terrestrial purposes, which we have already partly anticipated when briefly referring to the view telescopes, we shall find ourselves once more entering upon a field which the Jena Works have completely revolutionised by departing from the beaten track in a way which fairly dumbfounded the world. The effect was all the more sensational because it arose in a field which seemed to have resigned itself to inertia and a stagnant industry. To appreciate the significance of the progress which was initiated at Jena in 1893 we must ask the reader to follow us in a short explanation of a few simple optical principles.

When we view terrestrial objects through optical instruments we obviously wish to see them in their natural relations in space. That is to say, the objects must not be seen inverted and right and left must not be

interchanged. There are two ways of accomplishing this. The most obvious and direct way is to so devise the telescope that it may present to the eye an erect and unreversed image. The other course is to employ an astronomical telescope for the formation of the image and to append an optical device for erecting and reverting the image. The former idea is embodied in the principle of the Dutch or Galilean telescope, while the latter has been applied in the construction of the terrestrial telescope. Either type has its own particular advantages. The Galilean telescope consists simply of an object glass, which is nothing more nor less than a convex lens, and an eyepiece made up of a concave lens. Its main advantages are that it has a short body and is light in weight, thanks to its very simple nature. Optically it has, however, certain shortcomings, the worst of which are its small field of view and the want of uniformity in the lighting. These defects do not matter overmuch so long as the magnification is small, say $1\frac{1}{2}$ to 3 times, but they become rapidly more and more pronounced as the magnifying power of the glasses increases. In practice this type of glass is only used for purposes requiring a very moderate magnification, and hence Galilean telescopes are almost exclusively known in the form of opera glasses and ordinary field glasses. The astronomical or Keplerian telescope is free from these defects and furnishes uniformly bright images throughout its much larger field of view, the images are much more sharply defined, and there are other points of superiority, but it requires an erecting and reverting lens combination to

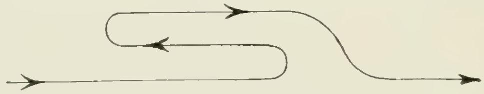


Fig. 79. A wire bent back upon itself.

render it available for viewing terrestrial objects. Such a set of lenses occupies a certain amount of space, and this space adds to the length of the whole, since the focal length of the eyepiece and that of the object glass occur as parts of a sum, whereas in the Galilean telescope these two focal lengths operate as a difference. It follows from this that the image-erecting astronomical telescope is unavoidably long and heavy, and unfortunately its length increases with the endeavour to reduce its magnifying power. Actually, therefore, this type is only used for producing terrestrial telescopes of high magnifying power, certainly not under 12 times, where an increased length does not constitute an insuperable objection. With lower magnifications the length would be such as to render the instrument quite intractable and useless in practice.

Here, then, there was a very undesirable gap, and it is not surprising that the question arose as to whether it was physically impossible to devise terrestrial telescopes, that is to say, telescopes of the image-erecting type, magnifying 3 to 16 times, yet of a sufficiently short body to produce a handy instrument. Now, one thing is certain, and that is that the distance which the light must traverse in order that the given conditions may be fulfilled and a certain magnifying effect produced cannot be shortened. At first sight then, the problem would seem to be incapable of a practicable solution, and yet a very simple likeness will enable us to glimpse the manner of its solution. Now, though a wire may be a yard long, it does not follow that its two ends are necessarily one yard apart. Obviously, by bending the wire its ends may be made to occupy any relative position. Indeed, as will be seen from the diagram in fig. 79, matters may be so arranged that a portion of the wire at one end forms the continuation of the portion at the other end. Translating this crude likeness of a wire doubled upon

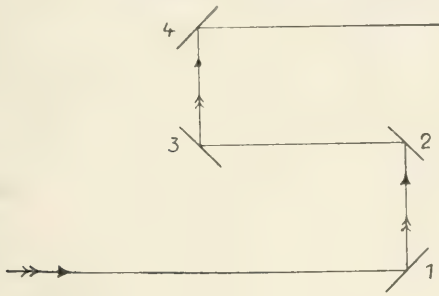


Fig. 80. Four successive reflections.

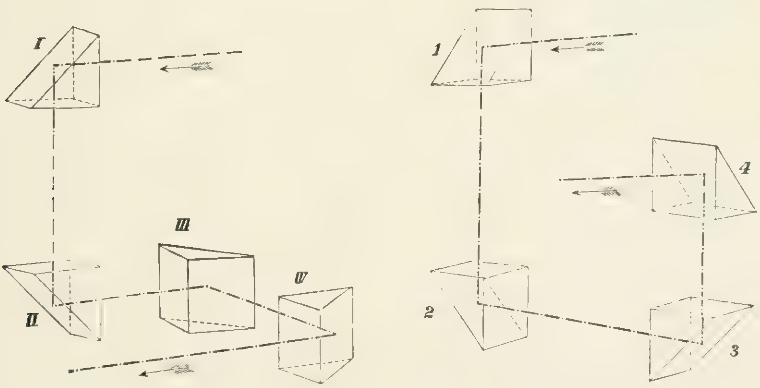


Fig. 81. Path of the rays through the Porro prisms.

itself into an optical device for doubling a ray of light upon itself, we forthwith realise that in order to render the optical image identical in position to the object we must employ *reflecting surfaces* in the place of lenses, for, whereas by refraction the rays can only be made to continue their forward motion, reflection enables us to impart to it a motion either

way, as indicated in fig. 80. Now, in whatever direction the light proceeds, the combined effect of the objective and eyepiece is governed by the sum of the component sections of the complete path, whereas the length of the instrument is equal to the difference between the opposed paths. If we follow up this fundamental idea it soon becomes apparent that ordinary reflecting *mirrors* consisting of glass coated with a metallic layer are useless in practice and require to be replaced by *prisms*. These allow the rays to enter and to reach the face opposite the right angle, where they are reflected at the surface where glass meets air, and whence they finally emerge through the third face of the prism. It will also be seen that we need four prisms in order to produce the re-inversion and re-reversion of the image, so that top and bottom, right and left may appear unchanged, and also to cause the light to proceed in the original direction from the object to the eye. Two prism combinations of the kind which fulfil these conditions and the course of the image-forming rays are sketched in fig. 81[1].

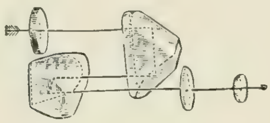


Fig. 82.
Optical arrangement of the prism field glass.

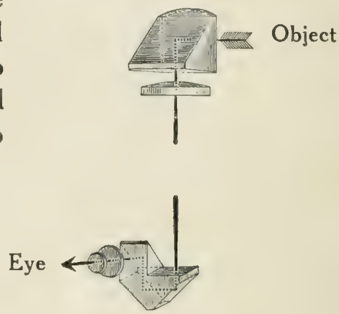


Fig. 83.
Optical arrangement of the stereo field glass
"Seeing round the corner".

It will be seen, — and this is more clearly indicated in figs. 82 and 83, — that the emerging ray proceeds in the same direction as the entering ray but it does not form its actual continuation. It is displaced to one side and causes the telescope to become dissymmetrical. At first sight it would seem that the solution of the problem is far from perfect, but, as has often happened in the history of inventions, what doubtless was an unavoidable defect in the original idea in the end turned out to be a means of securing most valuable effects.

[1] It is interesting to note that in the middle of the seventies of the past century, that is long before these prisms became publicly known, Abbe had such prisms made as well as a telescope equipped with them.

One of these effects arises already in the case of the monocular instruments, for it enables one, as it were, to *look round the corner*, thanks to that very dissymmetry of the telescope. When a continuous set of prisms is employed the optical displacement of the axes is only small, but it may be increased to any desired extent by purposely setting the individual prisms some distance apart. From the diagram in fig. 83 and the illustrations on pages 94 and those following it will be readily understood how these telescopes enable one to look over a wall or around some other impediment, and obviously this is an important advantage where the observer requires to remain unseen or under cover for his protection. On the other hand, where this particular advantage is not a primary consideration, the small displacement of the emerging, with respect to the entering, ray, as it occurs in the monocular field glasses of the type illustrated in fig. 84, is of no optical or practical moment whatever in view of the other more significant advantages of the new system.

1/2 act. size.
Fig. 84. Monocular Zeiss Field Glass.

The other valuable consequence of the optical dissymmetry of the telescope becomes apparent in the binocular forms of the prism telescope, which includes the popular field glasses. In these glasses one naturally arranges the two halves, for the sake of appearance, if for no better reason, so that the dissymmetry inherent in either component may disappear in the symmetry of the double telescope as a whole, as shown in fig. 85, where the displacement in the course of the rays is made to occur *towards the middle of the field glass* instead of being made to take place towards the right or towards the left in both members. The result of this arrangement is that the objectives are farther apart than the eyepieces. If we recall that our power of *appreciating differences of depth,* of enjoying *vision in relief,* depends upon the fact that we have two eyes which separately see objects from a slightly different standpoint, as touched upon on page 55, it will be realised that a prism binocular having its objectives farther apart than the eyes has the effect of artificially increasing the distance between our eyes to a considerable extent, thereby greatly *enhancing the solid relief* in which distant objects appear to the eyes.

In the Zeiss field glasses, which merit special interest, in view of the wide appreciation with which they have met throughout the world, the

distance between the objectives is about double that between the eyepieces, and hence they roughly double the natural power of seeing in relief. For certain purposes, for instance when surface-like bodies are to be viewed, glasses are so arranged that the distance between the objectives is less than that between the eyes. The various glasses are designed for use on travels, for watching sports and for hunting, as well as for use in the theatre and concert hall. Their manufacture has attained immense proportions. They are to be met all over the globet; here is no country where they are not in use; there is no modern army where they have not been introduced as service glasses.

The Zeiss field glasses are instruments of the highest precision and as such are necessarily extremely substantial in design and quality. Their bodies are made of *one piece* of cast light metal. The use of screws is carefully eschewed, so as to obviate any risk of the instrument ceasing to be impervious to the access of wet and dust. The external form of the instrument has naturally arisen primarily out of practical considerations, at the same time these have not rendered it difficult to give the instrument a pleasing appearance. The Zeiss field glasses are made in various models, magnifying 3 to 8 times, 12 times, 16 times and 18 times, and a very superficial comparison with the old field glasses of higher magnifying powers will suffice to make evident their pronounced superiority in the matter of handiness and the extent of their field of view.

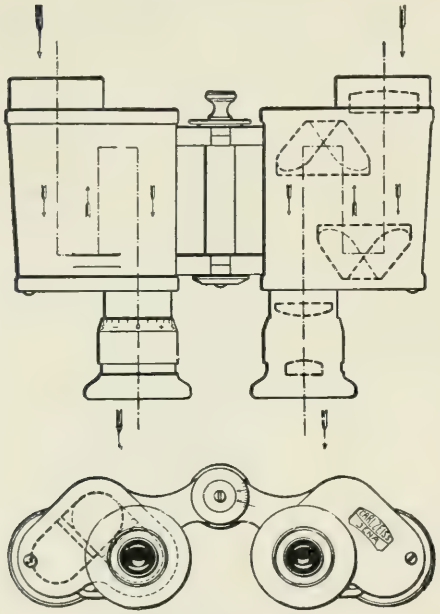


Fig. 85. Field Glasses.
Diagrammatic sketch of glasses as they appear when seen from the front and from above.

The glasses are fitted either with eyepieces which must be focussed separately or with jointly focussing eyepieces (fig. 86). The independent focussing of the eyepieces, apart from the very important point that they admit of adjusting the glasses to either eye separately, has the advantage that they can be mounted in a more watertight and dustproof manner. This ensures their safer use under all climatic conditions and renders them in particular adapted for use in the tropics. In addition, the

arrangement of the separately focussing eyepieces reduces the weight of the instrument to its lowest limits. The twin focussing device of the field glasses, on the other hand, has the advantage that the eyepieces, when

Fig. 86. Zeiss Field Glasses.
On the left with separately focussing eyepieces, on the right with twin focussing mechanism.

properly adjusted for either eye, may subsequently be rapidly focussed jointly when objects are to be viewed which move with great rapidity from or towards the observer, for instance when following the progress of race horses or rising aeroplanes. In both types of field glasses the distance between the two eyepieces can be varied and accurately adapted to the actual distance between the eyes. Two high-power types are represented in figs. 87 and 88.

Fig. 87.
The "Noctar" Binocular, magnifying 7 times, being a night glass of greatest light transmitting capacity.

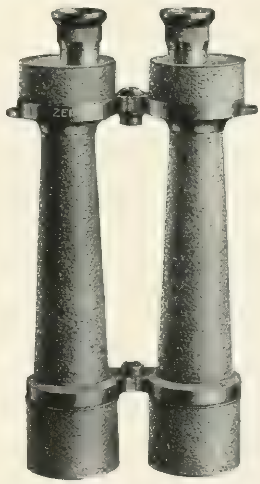


Fig. 88.
The "Delfort" Binocular, magnifying 18 times, being a view telescope.

In the case of theatre glasses there is no advantage in securing an enhanced plastic effect, since the distance between the stage and the spectator is relatively small. The Zeiss theatre glass, which bears the trade name "Teleater" (fig. 89), embraces at a distance of 20 yards a field of view of $4^1/_2$ yards, which is very much larger than that furnished by a glass of the old Galilean type.

Incidentally the case of these prismatic glasses is instructive as illustrative of the curious manner in which the inceptions of the inventive mind often develop before they reach the stage of concrete achievements. Neither the idea of prismatic image erection nor that of increasing the plastic effect by setting the objectives farther apart originated at Jena. The combination of prisms which formed the crux of the new telescope had been thought out many decades previously by an Italian engineer named Porro, a fact which, however, was not discovered until the new invention came to be subjected to an official search when it was sought to protect the invention by an application for letters patent. Likewise, the principle of stereoscopic seeing applied in the new glasses can be traced to no less a mind than that of Helmholtz, who had made it the basis of his "stereo-telescope". But it remains a fact that neither Porro's nor Helmholtz's inventions ever attained any practical significance, since, taken by itself, neither was of sufficient practical value to ensure its survival. The true value of the invention lies in the association of the two ideas, or, we might say, in the realisation of a Helmholtz stereo-telescope with the aid of Porro prisms. The achievement of this combination is the indisputable merit of Prof. Abbe and the Zeiss Works.

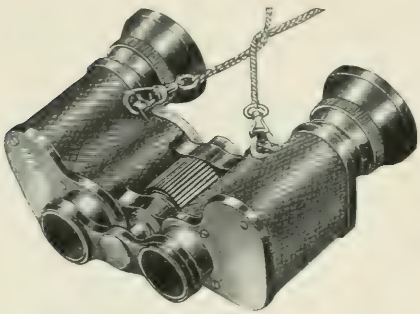


Fig. 89. The Zeiss Teleater theatre glass, magnifying 3 times, 1/2 act. size, weight 7 1/2 ounces.

A further notable advance was made about the middle of 1920, when the 70-degree eyepiece invented in 1917 by Dr. Erfle was made to furnish a means of bringing out the Zeiss wide-angle field glasses. These glasses, though scarcely heavier than the older standard glasses, embrace a field of view which is half as large again or, to put it in another way, the glass magnifying 8 times has a field equal in size to that of the standard glass magnifying 6 times.

While telescopic sights for ordnance and machine guns have been known for years, oft expressed wishes on the part of sporting men were required to induce the Zeiss Works to devise lens telescope sights for hunting purposes. The usual sighting devices require the rifleman to perform the impossible feat of seeing three things at the same time, viz. the back sight, the fore sight and the quarry. The advantage of the telescope sight is that the target and the sights appear in the same plane. In consequence,

the eye may remain adjusted for a single plane and is therefore subjected to less fatigue, which conduces to good and steady aiming. There is the further advantage that, being magnified, the target is seen with far greater distinctness, and errors such as arise in consequence of full and fine sighting or holding the barrel in a skew position are obviated. From this the reader will be able to appreciate the great superiority of the telescope sight over the optically unaided sight (see figs. 90 and 91).

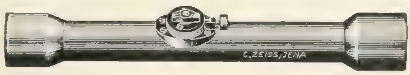


Fig. 90. "Zielvier" Telescope sight. Magnification $\times$ 4, field of view 10·8 yards at 100 yards distance; light-transmitting capacity 59·3, length 270 mm. (10½ inch.); weight 12¼ ounces.

Fig. 91. The "Zielmultar" Telescope sight. Magnifying $\times$ 1 to 6, length 335 mm. (13¼ inch.); weight 1¾ lbs. An all-round telescope sight for heavy sporting guns.

The advantages of the new *prism field glasses* for military observations met with early recognition and promptly led to supplies to the military authorities of all countries of the world. These supplies led not only to the construction of new instruments of observation adapted for special military requirements, but also to that of a great variety of optical directing and measuring appliances of a new or improved kind, especially for artillery requirements. Prominent among these new instruments were telescope sights and range finders.

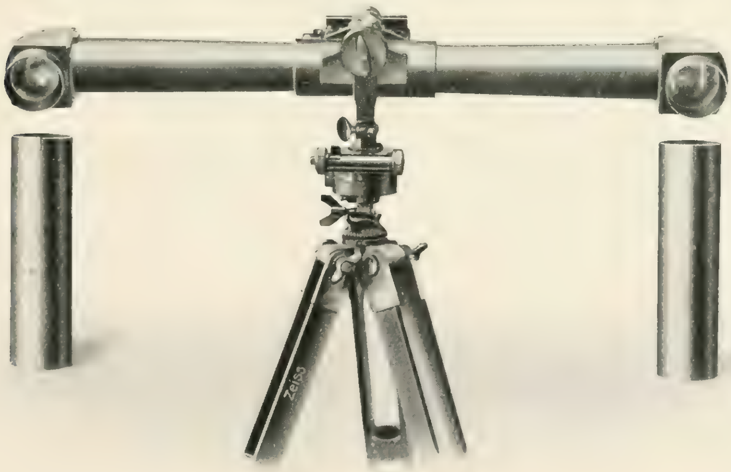


Fig. 92. Shear-jointed (Stereoscopic) Telescope. About ⅛ act. size.

By the terms of the Peace Treaty Germany forfeited the right of making and supplying war materials to other countries. On the other hand, the Zeiss Works holds the sole concession for the supply of optical war instruments for the use of the German home defence army as well as the German navy. It may be interesting to give a brief survey of the optical instruments which have been designed for use in the army and navy, with

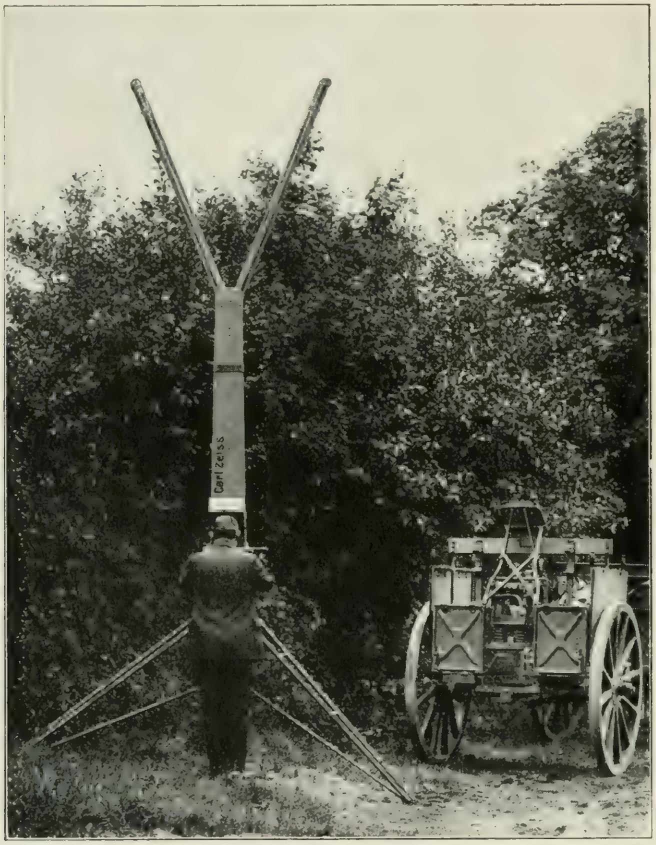


Fig. 93. The Hyposcope. About 1/50 act. size.

the exception of the field glasses, which have already been described in preceding pages.

At the time when the prism field glasses were put on the market, viz. in 1894, the shear-jointed telescope was brought out as well, though at that time only in the form of a hand instrument. Both in this form and, more extensively, as a stand telescope (fig. 92) mounted on a stand fitted with director and clinometer, as employed in artillery, it has become an

indispensable instrument for military observation. This instrument can be used in two positions. When the two arms are in their extended position, so that one is in alignment with the other, the distance between the objectives is about 10 times greater than that between the eyes, and consequently the plastic effect is very much more pronounced than that obtained in the field glasses. When its two hinged arms are folded up it serves for making observations under cover.

Fig. 94. Mast Telescope. About $^1/_{265}$ act. size.

The *Hyposcope* shown in fig. 93 is an exaggerated variety of the shear-jointed or relief telescope. This large instrument was designed to take the place of the insecure observation ladders which were used to assist the operations of the artillery. Its dimensions are such that when set up on the ground it affords a highest look-out of $16^1/_2$ feet above the ground, or more if set up on a car. It lends itself for observation with

the objective arms in any position which will afford the required cover. While passing from the upright to the extended position of the arms it is interesting to watch the continuously gradual increase of the stereoscopic effect. Certain lenses can be folded out of action, when it is desired to obtain a less highly magnified but more general view of objects comprised within a wide angle.

Observations may be made from much greater altitudes by dispensing with binocular seeing. The mast telescope shown in

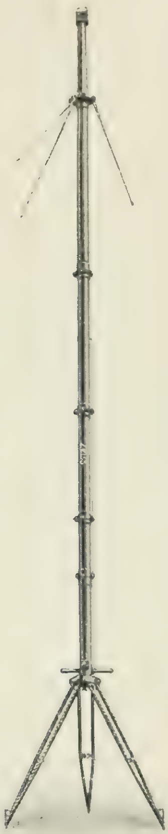


Fig. 95.
About 1/50 act. size.

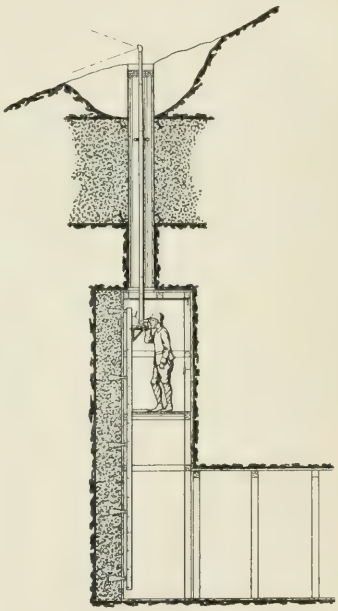


Fig. 96.
Periscope Tube in a pit.

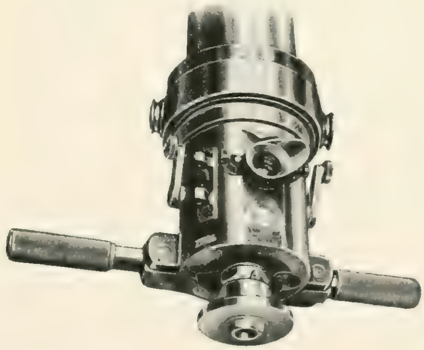
Monocular Field Periscope Tube, Observation telescope magnifying $\times$ 10 for use in pits, etc. with telescope tube of variable length.

fig. 94 enables observations being made from heights of 30 to 85 feet. The mast is mounted upon a car specially designed for its accommodation. For transport the mast telescope can be folded down, while during observation the car serves as the base for the mast in its extended state. In view of the necessarily large diameters of the lenses, these are accommodated

in separate upper and lower sections attached to the outside of the mast. For bringing the object into view the mast can be rotated and the objective mirror tilted by telescoping transmission rods carried by the mast. The Field Periscope shown in figs. 95 and 96 is adapted for monocular observation from lower altitudes. It serves for observation from an understructure, from elevated positions on tree stems, and from stands under cover. The altitude of the look-out can be varied with the aid of tube-sections 13 to 20 feet long.

Particularly exacting requirements have to be satisfied in the optical and mechanical construction of the periscope tubes of submarine boats, as indicated in fig. 97, especially when it is realised that these are in every sense the eyes of underwater craft. The principal magnification is one of $1^1/_2$ diameters, which is required to see the external objects within a large view angle of 40^0 in their

About 1/60 act. size.



About 1/10 act. size.

About 1/20 act. size.

Fig. 97. Monocular Periscope for Submarines.

natural size, since objects viewed through a tube appear smaller than they really are. By a mechanical change of lenses the magnification can be raised to $\times$ 6. The optical portion is contained within a nickel-plated tube of a length of $19^1/_2$ to 23 feet long and is impervious to air or water under compression. To reduce the water pressure the tube tapers at its upper end. The tube can be pushed in and out according to the required

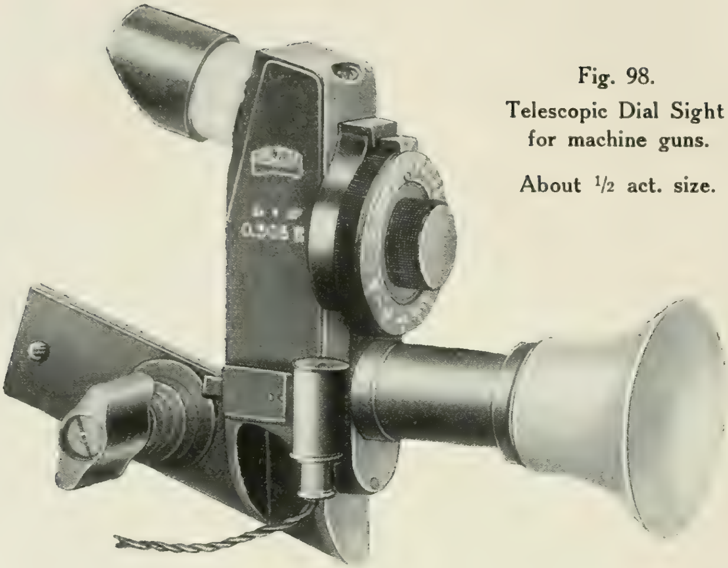


Fig. 98.
Telescopic Dial Sight
for machine guns.

About 1/2 act. size.

look-out height above the water, and while travelling at considerable depths below the surface the tube can be drawn in completely. The observer either participates in the motion of the tube portion, the tube being then mounted on the elevator principle, or the rays are directed into a stationary eyepiece, the arrangement then forming a stationary periscope.

Sighting Telescopes and Directors.

In view of the enormous cost involved, no attempt was made before the World War to equip army rifles with lens sighting telescopes similar to those fitted to sporting guns. Machine guns and field guns as well as naval guns are now invariably furnished with sighting telescopes. The telescopic sight, as shown in fig. 98, has a button above the eyepiece, with the aid of which the sighting line may be so set to the range that the gun, when laid, may deliver the projectile along the proper trajectory. The telescope has an attachment for illuminating the graticule at night as well as a spirit level to ensure against tilting. Land service guns are now mostly operated from under cover, so that aim is taken indirectly by reference to a rearward auxiliary target, since the forward outlook is restricted by the shield. The direction of the target is sent down from a distant observing station or it is taken from the ordnance map. The most

extensively used and best known director telescope is the dial sight, large numbers of which have been produced at the Zeiss Works. Its great advantage lies in the fact that the gun layer need not change his position with respect to the eye end of the telescope, no matter what the direction of the sighting line may be. With the dial sight the gun can be laid by the direct as well as the indirect method. The latter is the one which is more commonly applied, and this is done in conjunction with a director compass. For this reason the objective prism is so mounted that it can be swung in an arc. It may be swung along a graduated scale, either right round by hand, or more precisely, with the aid of a tangent screw. To obviate any "leaning" of the image the optical system includes an Amici reversing prism coupled for half a side turn. The objective prism can, moreover, be tilted in altitude by amounts shown on a scale. When set up in a horizontal attitude the instrument serves as a sighting telescope for anti-aircraft guns (figs. 99 and 103). The objective only is directed upon the target, while the eyepiece retains its convenient horizontal position. The sighting telescopes for use on board ship have generally an eyepiece arrangement giving a continuously variable magnification ranging from 4 to 20 diameters. Instruments of this kind, so-called pancratic sighting telescopes, are shown in figs. 100 and 101. In the case of garrison sighting telescopes the barrel requires to be sufficiently long to reach close up to the embrasure in order that the field of view may not be encroached upon by the narrowness of its opening. In most cases a straight telescope is associated with one having the eye or eyes applied transversely at the side, one being for sighting in elevation (Gunner No. 1), the other for transverse sighting (Gunner No. 2). Sighting telescopes for submarine guns require to be watertight under a hydrostatic pressure of 15 atmospheres. Naval sighting telescopes are generally equipped with double eye protectors and coloured glass changers.

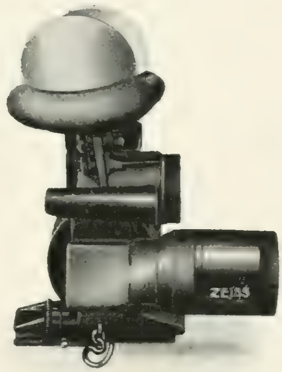


Fig. 99.
Sighting Telescope for anti-aircraft guns.
About 1/4 act. size.

The parallelism of the sighting line and the centre of the gun-bore may be verified with the aid of special adjusting devices of the kind illustrated in fig. 104. These are in the form of two plug pieces, by means of which the bore of the gun is transformed for the time being into a sighting telescope. After directing the gun with its temporary sighting

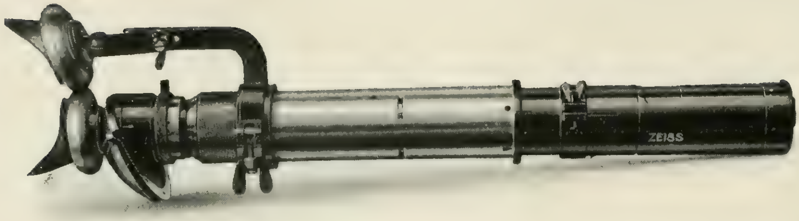


Fig. 100. Pancratic (Variable-power) Embrasure and Turret Sighting Telescope.
About 1/6 act. size.

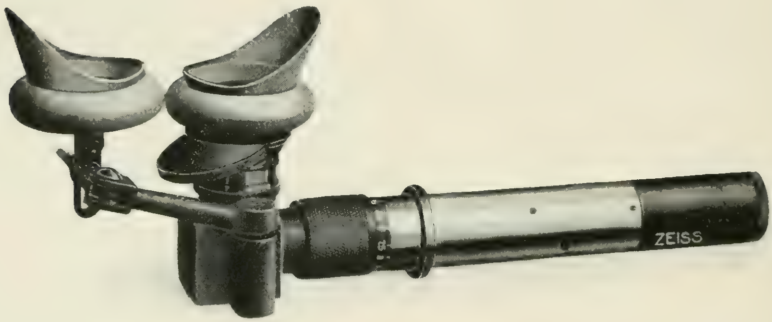


Fig. 101. Pancratic Sighting Telescope for lateral application of the eye.
About 1/6 act. size.

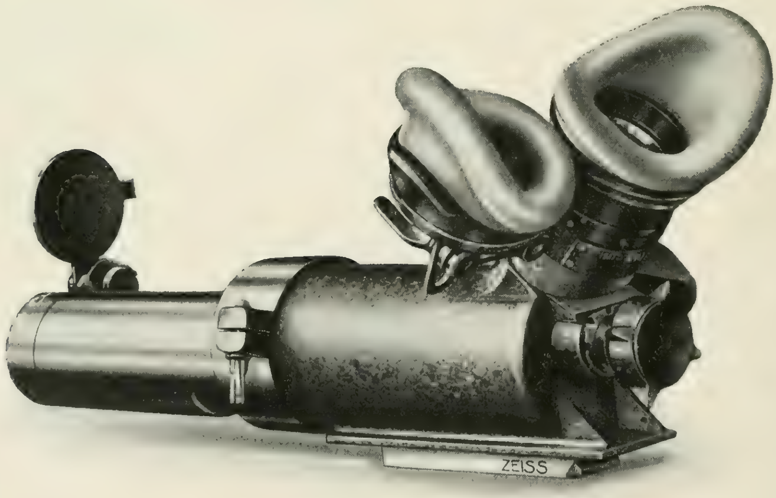


Fig. 102. Submarine Sighting Telescope.
About 1/3 act. size.

plugs upon a distant object or upon sighting targets, the optic axis of the sighting telescope can be brought into agreement with the centre-line of the gun barrel. On board ship, where sighting targets cannot be set up without difficulty, the sighting lines which are to be verified or rectified are rendered coincident by optically displacing one parallel to the other. This is done with the aid of the additional tube shown in fig. 105.

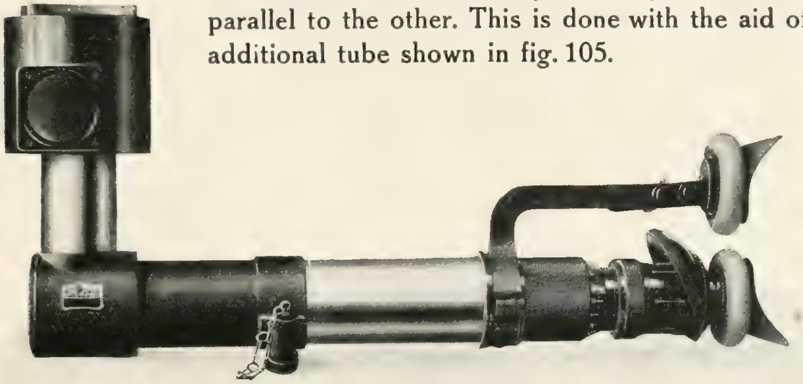


Fig. 103. Pancratic (Variable-power) Elbow Sighting Telescope.
About 1/5 act. size.

Compass mark-pointers (fig. 106) are employed for laying land service guns by the indirect method of sighting. This instrument serves for ascertaining and sending down the battery angles. In order to ascertain the positions of the enemy's fire, night angle-of-sight instruments, as shown

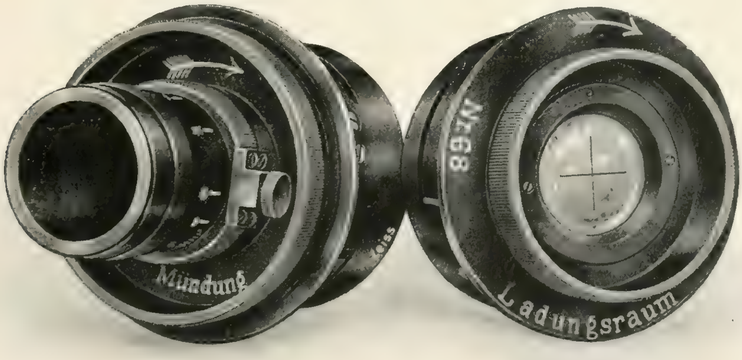


Fig. 104. Gun Sight Adjusting Device.

in fig. 107, are set up at various points of observation separated by appropriate distances. In this case the sighting telescope is replaced by a collimator which supplies a reference mark at infinity Observations may thereby be made with the unaided eye, while the exact position of the eye is a matter of little moment. From the data so ascertained the position of the gun may then be found by graphic means. The Map Sighting Telescope (fig. 108), designed for determining from the coast the position of targets at sea, operates in much the same manner.

On warships the advantage of a strictly central firing order has led to the development of a system in which the line of sight is determined at a central point of observation and thence transmitted electrically to the individual guns.

The Direction Indicating Periscope (fig. 109) is a combination of a binocular telescope for the

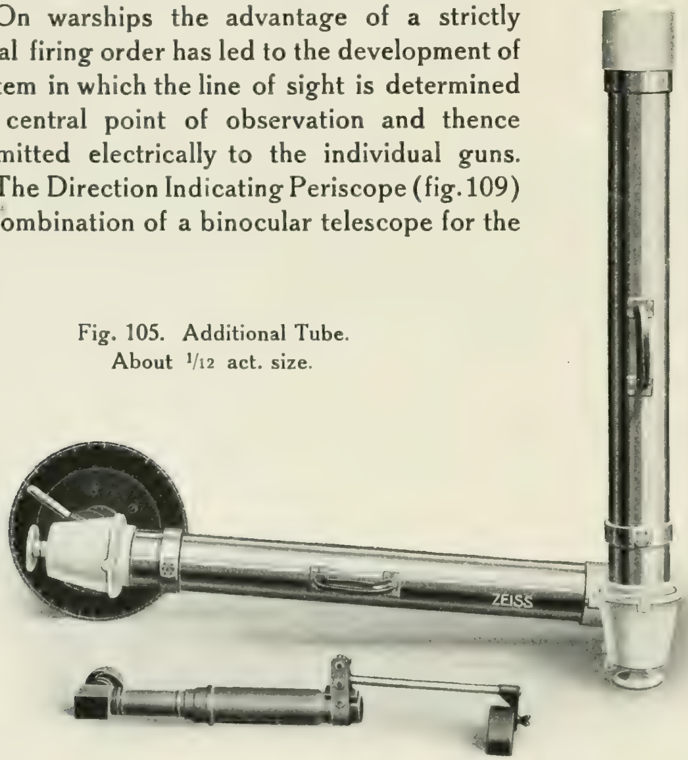


Fig. 105. Additional Tube.
About 1/12 act. size.

artillery officer and a monocular telescope with eyepiece on the right and left side for the gun-layer. Both telescopes give continuously variable magnifications and are, in addition, provided with lens attachments which, when put in operation, furnish an extensive general view under a much diminished magnification.

When firing upon air-craft it is a very difficult matter to make a correct allowance for the progress of the moving target. The latter moves

at a high speed in solid space. Between the instant that the position of the target has been determined until the bursting of the shell the aircraft covers a long distance. The problem which arose was therefore to devise a means by which the mathematically rather involved orders for line,

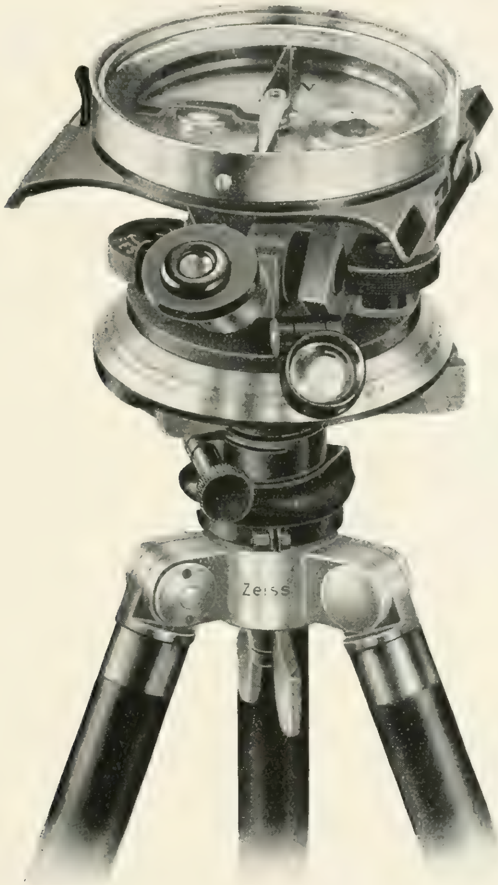


Fig. 106. Compass Mark Pointer.
About 1/2 act. size.

elevation and fuse timing may be arrived at automatically and in a minimum of time by a special sighting instrument.

The deviation reading instrument shown in fig. 110 is designed for direct aiming and involves primarily a measurement of the component angular velocities of the moving target.

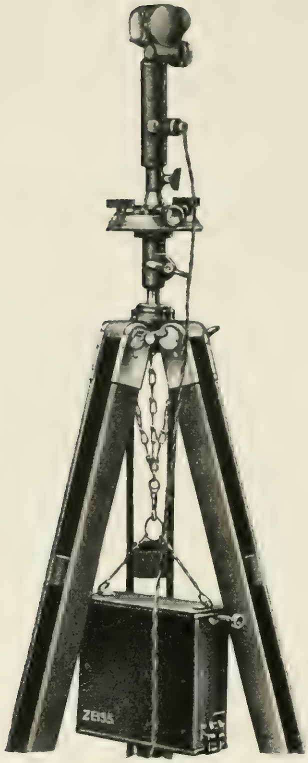


Fig. 107. Night Angle-of-sight Instrument. About 1/5 act. size.

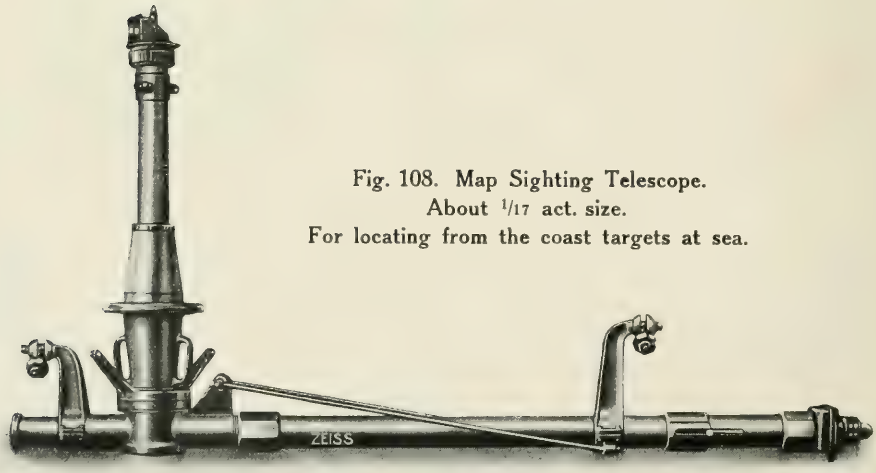


Fig. 108. Map Sighting Telescope.
About 1/17 act. size.
For locating from the coast targets at sea.

Fig. 109a.

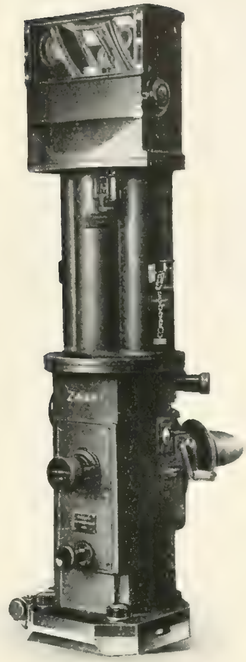
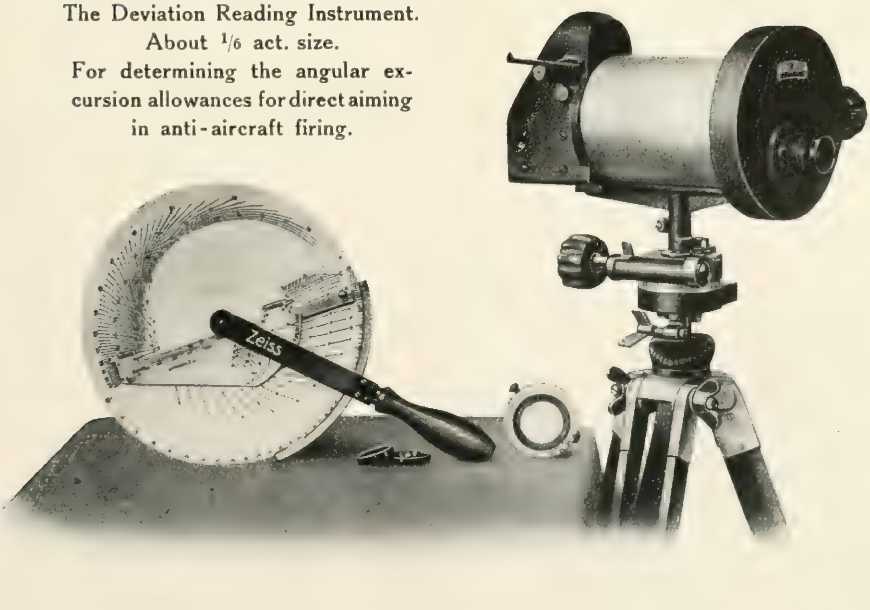


Fig. 109b.

Fig. 109a and b.
Direction Indicating
Periscope.
About 1/10 act. size.

Fig. 110.
The Deviation Reading Instrument.
About 1/6 act. size.
For determining the angular excursion allowances for direct aiming in anti-aircraft firing.



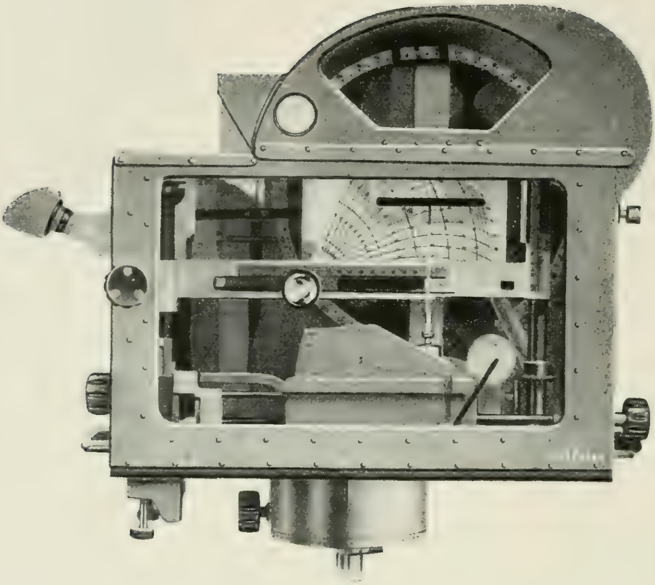


Fig. 111. The A. A. Group Order Instrument. About 1/8 act. size.

The A. A. Group Order Instrument shown in fig. 111 is designed for indirect aiming and involves in its inception the determination of the direction and linear velocity of flight.

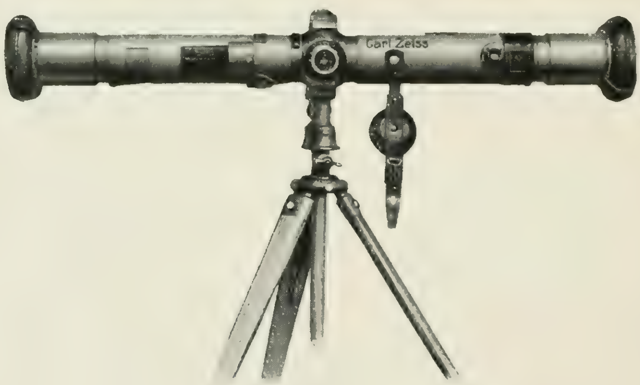


Fig. 112. Invert Rangefinder with 70 cm. (28 inch.) base.
For infantry use. About 1/10 act. size.

Rangefinders.

It is no more good practice in these days to fire without a rangefinder upon targets in the air or upon the sea, and elsewhere the use of a rangefinder greatly reduces the number of wasted trial shots required to get the range of a target. The rangefinders derive their power of reading distances from the difference in the directions in which a target is seen from the entrance windows at the ends of a transverse double telescope, in other words, from the angle which the distance between these entrance windows or the base subtends at the target. The exactness of the readings increases with the length of the base and the magnifying power of the telescopes. In the rangefinders designed for use on warships and on coast-guard stations this base and magnifying power can be carried much further than is possible in the case of infantry rangefinders. On the other hand, naval observations require a far higher degree of exactness. In practice the degree of exactness should be such as to enable the instrument to accurately read differences of direction, or the so-called angle of parallax, to one second of an arc. It should not therefore surprise us that it has required many years of costly experiments and the unstinted use of the most advanced resources of modern technique to elaborate an instrument, optically and mechanically perfect to at least this extent that its readings, beside being correct, should not be affected by vibrations and changes of temperature. We may distinguish stereoscopic

Fig. 113. Trench (Invert) Rangefinder with 50 cm. (20 inch.) base. For infantry and bombers.

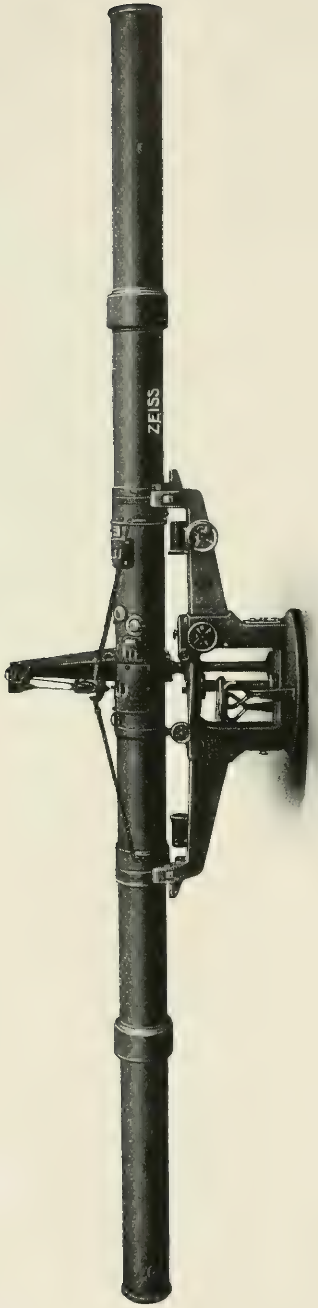


Fig. 114. Coincidence Rangefinder with 10 metre (33 foot) base.
For coast batteries. About $^1/_{60}$ act. size.

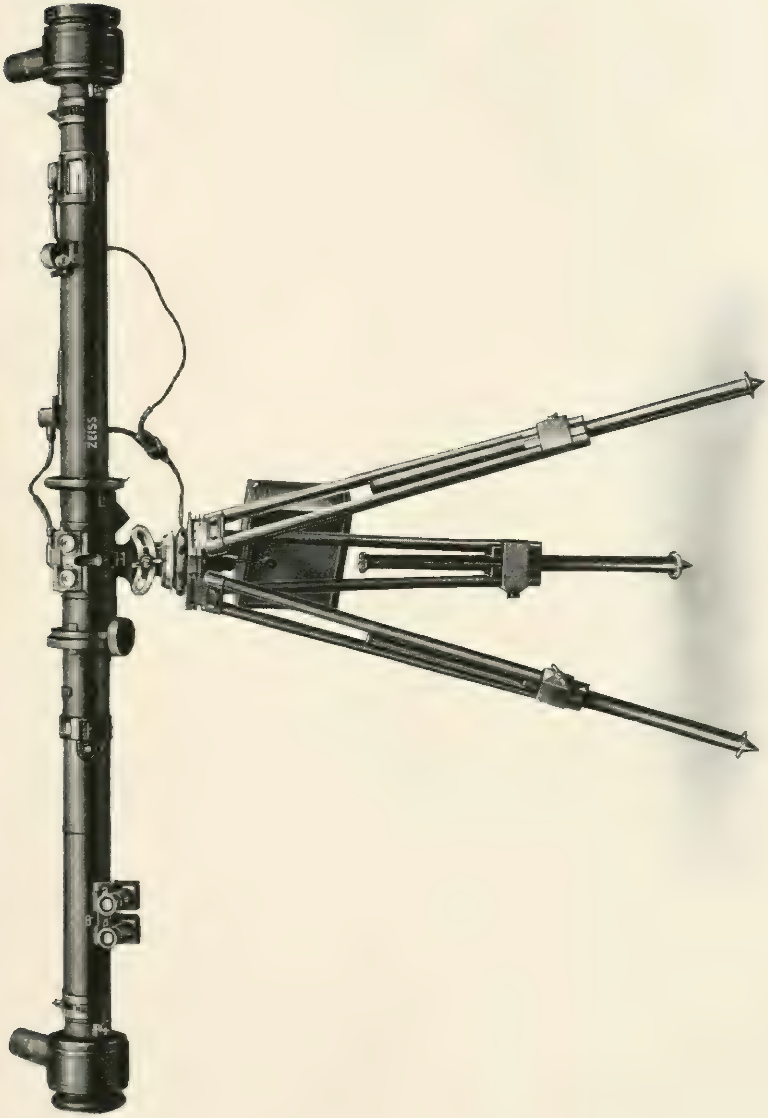


Fig. 115. Stereoscopic Rangefinder with 2 metre (6 $^1/_2$ foot) base.
About $^1/_{15}$ act. size.

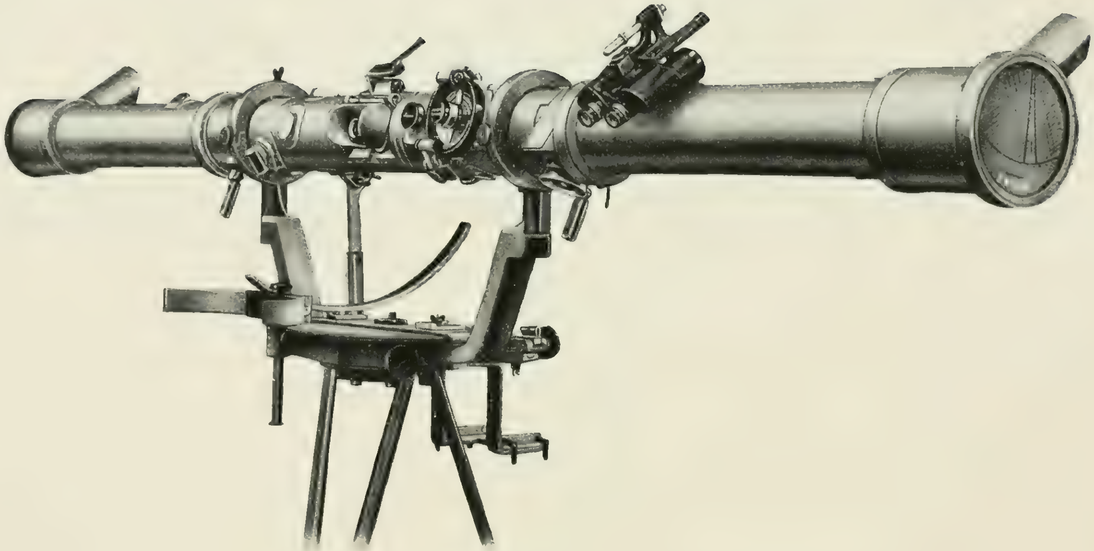
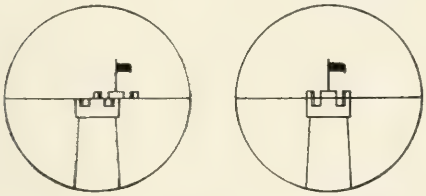


Fig. 116. Stereoscopic Rangefinder with 3 metre (10 foot) base, with obliquely set eye tubes and elevation reader. With movable mark. For use on board ship. About $^{1}/_{15}$ act. size.

rangefinders and half-image rangefinders. In the former group a double telescope is used, either eyepiece of which is furnished with a mark of reference. When the left image of the sighted object coincides with the left mark of reference, the right image of the same object will appear a little away from the right mark of reference by an amount depending upon the angle of parallax and hence the distance. If now the latter be displaced until it coincides with the image of the sighted object in the same manner as the left, the requisite displacement will furnish a measure of the distance. When the



not set Fig. 117. set for coincidence

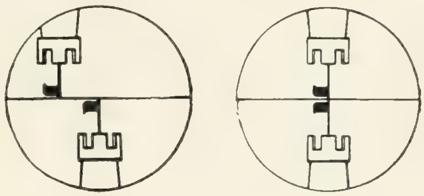
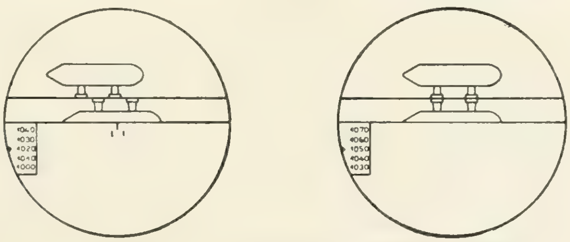


Fig. 118.

images are viewed with both eyes the images of the landscape become fused into a relief image, and the same applies to the reference marks. When taking the range the impression is created as though the mark wandered within the landscape in the direction to and from the observer, i. e. along the direction of sight, and all that is necessary is to note whether the mark appears at the same distance as the sighted object. This arrangement is called the "wandering mark", and this term has been retained



not set Fig. 119. set to coincidence

in reference to the established modified arrangement, though, instead of one of the marks being shifted, one of the images of the object is displaced by the deflection of the rays. This arrangement has been in extensive use, more particularly for directing the operations of anti-aircraft batteries. The German warships which took part in the battle of Jutland were likewise equipped with this type of rangefinder. Although this mode of measurement embodies most nearly the conditions of natural seeing, it nevertheless requires very good training on the part of the operator.

Moreover, before the war doubts had arisen as to whether good readings would result in the heat and excitement of battle. Events, however, have disproved these fears. Thus, whilst originally the manufacture of rangefinders at the Zeiss Works had been restricted to this stereoscopic telemeter principle, which had been invented by Grousilliers in 1892, the establishment later proceeded to make rangefinders designed on the half-image principle. These rangefinders were adopted by the military authorities of a number of states. The manner in which the instrument is set for taking readings may be seen from figs. 117 and 118. One of the objectives forms one image, the other objective forms the other partial image. One of the partial images is then shifted to one side until at the line of separation it stands exactly above or supplements the other partial image. With most objects, such as occur in the open field,

Fig. 120. Electrical Signal Flashing Apparatus with 130 mm. (5 1/4 inch.) mirror. (About 1/13 act. size.)

it is an advantage to let the upper image stand on its head. In the case of air targets, on the other hand, it is better to let the lower image be the one which appears inverted, as shown in fig. 119. Rangefinders for field artillery are mostly arranged for taking the ranges of field and air targets. Figs. 112 to 116 exemplify various rangefinders constructed on this principle. The exigencies of trench warfare have led to the development of rangefinders on periscopic lines.

Signalling Apparatus.

The introduction of wireless telegraphy notwithstanding, optical signalling appliances still retain considerable importance. The signals are formed by momentary or sustained uncovering of a source of light in imitation of the dots and dashes of the Morse code. In heliographs the sun is the source of light, which has, however, the disadvantage that it is not always available. In the earliest forms of the apparatus as made at Jena the source of light was an oxy-acetylene flame, but in the modern signalling mirrors electric light is exclusively employed. A parabolic mirror is employed to render the projected rays as nearly parallel as possible.

The electrical signal flasher (fig. 120) has a mirror 130 mm. ($5^1/_4$ inches) in diameter and is furnished with a battery to supply current to a 16-c. p. filament lamp. The apparatus is provided with larger and smaller mirrors according to the required range. In some cases the current is furnished by a treadle or hand-driven dynamo.

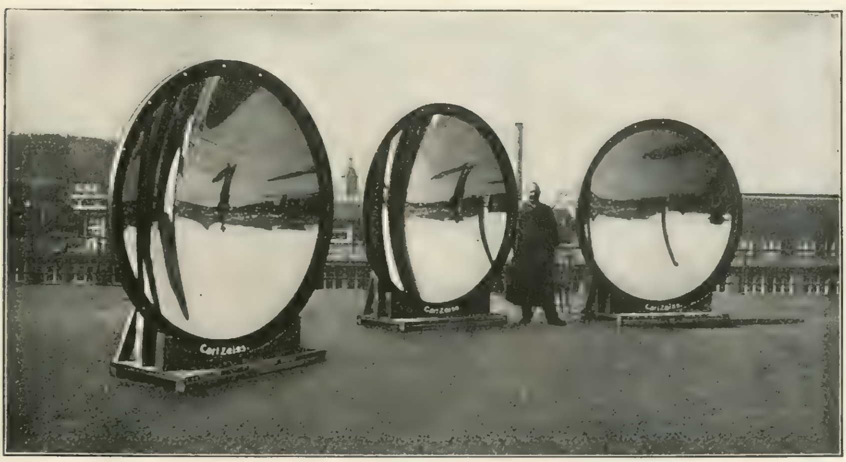


Fig. 121. Projector Mirrors $6^1/_2$ ft. in diameter for electrical searchlights.

Searchlights and Triple Mirrors.

We now come to another species of apparatus which is of the utmost importance in warfare. These are the *projectors* or so-called *searchlights*. They are furnished almost exclusively with silvered concave glass mirrors. In the best projectors made at the Zeiss Works the exposed front surface is strictly parabolic, while the silvered back is a figured parabolic surface of such a profile that nearly the whole of the undesirable secondary reflections are made to coincide with the primary reflected beam of light. Hence the name 'paraboloid' mirrors. The parabolic mirrors made at the Zeiss Works have two parabolic surfaces, but apart from these, others are made having a spherical and a figured (non-spherical) surface. These spheroidal mirrors naturally give rise to a highly disturbing front reflection. The source of light employed with the projectors varies according to the conditions under which they are used. Oxy-acetylene searchlights are fitted with a radiating body which is rendered incandescent by an oxy-acetylene flame. These searchlights are favoured where the range is not very great and where it is essential that the apparatus should be portable and self-contained.

Fig. 122. Triple Mirror Apparatus. About 1/12 act. size. Optical signalling device, without a self-contained source of light, for making signals with the aid of the light of the opposite (receiving) station.

The electrical searchlights supplied by the General Electrical Company of Berlin were all furnished with Zeiss projector mirrors (fig. 121). In connection with signalling appliances and searchlights another device with peculiar optical properties has come into prominence. These are the so-called triple mirrors. They consist essentially of a piece of glass having

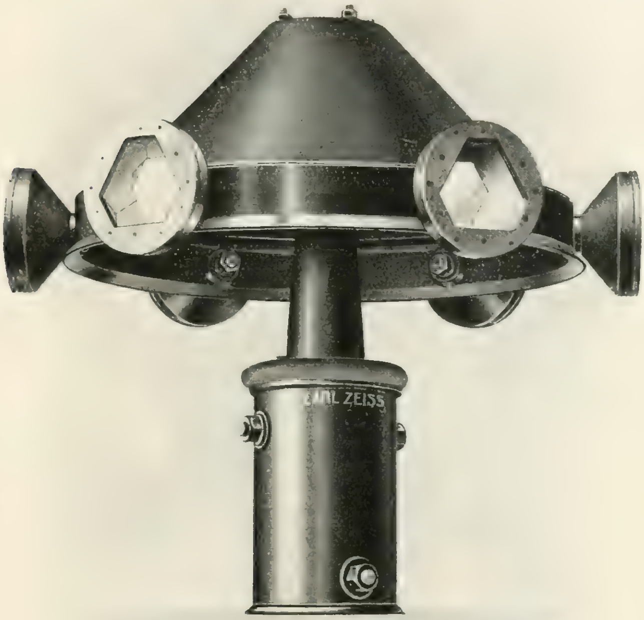


Fig. 123. Triple Arrangement for Navigation Buoys.

three polished pyramid surfaces at right angles to one another and a polished base. All rays proceeding from a distant source of light and falling, not too slantingly, upon the base, emerge from the glass body after reflection at the three pyramid surfaces, in a direction which is accurately parallel to the incident ray and return to the source of light. The outstanding feature of this device is that this return to the source of light occurs without necessitating any particular adjustment of the triple mirror. An eye looking into it, however it may be held, will always see its own reflection.

The following applications of the triple mirror may serve to illustrate its great utility in certain cases. The triple mirror signalling apparatus shown in fig. 122 has in front of the triple mirror a shutter device by means of which the incident light proceeding from the opposite station may be turned into signals in terms of the Morse code. A station which is furnished with a triple mirror attachment in the place of a source of light of

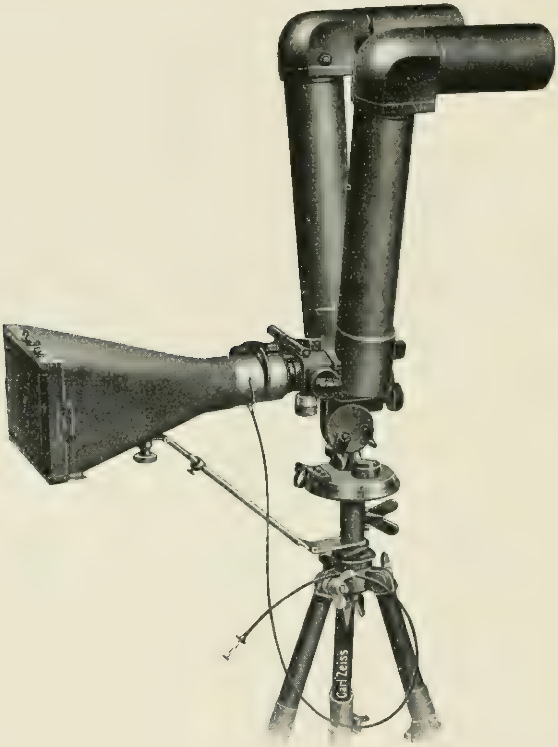


Fig. 124. Shear-jointed Telescope Camera for 12×9-cm. plates. f = 20 cm. About 1/8 act. size.

its own is thus enabled to transmit optical signals with light provided by the receiving station.

The triple mirror arrangement for navigation buoys (fig. 123) consists of six triple mirrors mounted in gimbals. It is set up on the top of navigation buoys. The triple mirrors facing a vessel are seen from the latter brightly illuminated as soon as the beam of the ship's searchlight meets the buoy. The latter thus fulfils its directive purpose without being furnished with a source of light of its own.

Military and Naval Photography.

Like almost every other branch of applied science, photography has entered more and more into the science of the conduct of war. The shear-jointed or relief telescope camera serves to record observations on a photographic plate. The exchange of communications between observers and commanders is thereby greatly assisted, and changes in the field can be ascertained with greater precision. Very serviceable photographs can be obtained in series form. The camera, as shown in fig. 124, is very light and furnishes pictures corresponding to a focal length of 2 metres ($6^1/_2$ ft.).

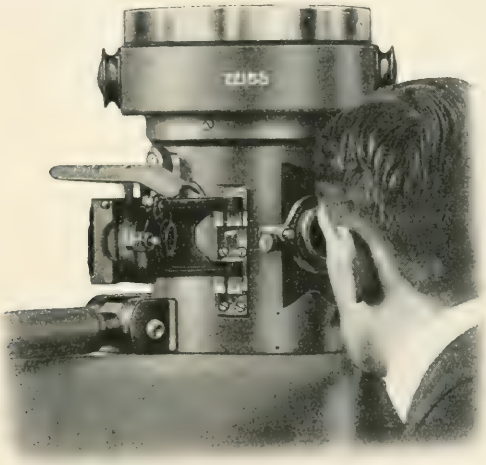


Fig. 125. Submarine Camera $6 \times 4^1/_2$ cm., f=4 cm.
About $^1/_6$ act. size.
For photographically recording observations made with the periscope.

The best pictures result with dark-yellow filters and at an aperture of F/70. The submarine camera shown in fig. 125 furnishes a documentary record of the circumstances of a torpedo attack. Photography from aircraft attained great importance during the war as a means of reconnaissance. In a measure as it became necessary to take the photographs from ever increasing heights the focal lengths were steadily increased until they attained

a maximum of 70 cm. (28 inch.). A camera of this kind is shown in fig. 126. Also, instead of photographing with hand-cameras held in a slanting attitude in the hands and converting the resulting greatly distorted photographs by a process of corrective photography into maplike records, the larger modern cameras were suspended from the aircraft in a vertical attitude and directed by hand.

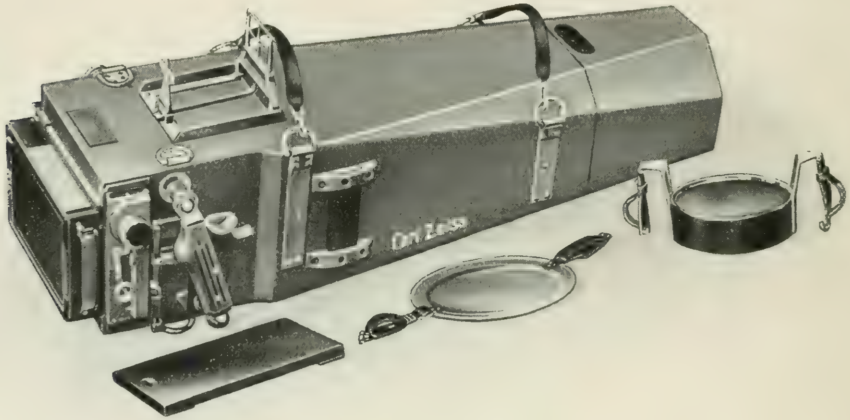


Fig. 126. Aircraft Camera, 18×13 cm., f=70 cm.
About 1/10 act. size.

Fig. 127.

The Auto Department.

In course of time the manufacture of searchlights for military purposes gave rise to the development of projector lamps for use as headlights for motor vehicles. From the very novelty of the optical principles embodied these new headlights produced considerable stir at their first appearance in 1911. Obviously, the value of a motor vehicle is greatly enhanced by speeds being attainable on country roads at night comparable to those at which the cars can be run in daytime. This implies the existence of headlights capable of throwing a powerful beam of light a long distance ahead, as indicated in the picture at the head of this section. In more or less densely frequented localities, notably in towns and villages, the lamp is only required to light up a short space in front of the car, since the permissible speed is very restricted, and, in addition, persons and horse vehicles coming towards the car should not be dazzled. For this reason the use of glare-producing headlights in much frequented localities has in recent years been prohibited by police regulations all over the globe. Even when travelling along open country roads it should be easily possible to promptly cut off the glare when two cars meet. From this it follows that a device for cutting off the glare is not less important than the intensity of the beam which the headlight is capable of throwing forward.

Optically the Zeiss projector head lamp consists of a principal reflector and an auxiliary reflector (figs. 128 and 129). The principal reflector is a parabolic glass mirror silvered on the back. The auxiliary reflector in the case of the acetylene projector head lamp is a hemispherical glass mirror which throws back upon the principal mirror nearly the whole of the rays which are not received by the principal mirror, whereby the intensity of the illumination is enormously increased. The auxiliary mirror can be swung radially about the flame through an angle of 180^0, and when it has reached this position no light can pass from the flame to the principal mirror. The head light will then be free from glare.

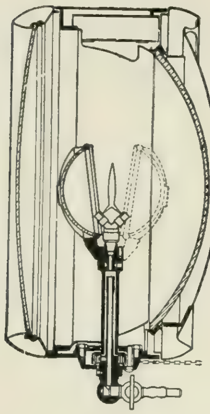


Fig. 128.

Diagrammatic cross-section of the acetylene projector head lamp. The full lines show the auxiliary mirror in its principal (full-light) position, while the dotted lines indicate its non-glare position.

In the electrical projector head lamps (fig. 130) the bulb of the filament lamp itself is made to serve as the auxiliary mirror. To this end the front half of the bulb has an annular silvered zone, which throws back upon the principal mirror the rays which issue from the flame in a forward direction. Hence full account is taken of the whole of the light which issues from the flame. The central front portion of the bulb surface is of the size of the base fitting. It is left unsilvered and is mat, so that the light which otherwise would be reflected upon the base fitting to no useful purpose is allowed to pass out through the mat window and thus becomes available for forward illumination.

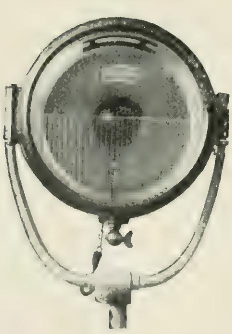


Fig. 129
Acetylene Projector
Head Lamp.

Fig. 130
Electric Projector
Head Lamp.

Fig. 131
Electrical Spot Lamp.

In the case of the electrical projector headlights the glare is even more pronounced than it is in that of the acetylene projectors, so that in their case a device for cutting off the glare becomes an even more important matter. In the Zeiss system this is accomplished by pushing a yellow glass cylinder with a windowed metal cap over the unsilvered portion of the filament bulb. When this happens only a portion of the light falls upon the principal mirror, which then shines with a yellow colour. The resulting yellow light is amply sufficient for driving through towns and even for rapid travelling, while at the same time it is entirely free from glare. Since it so happens that yellow light penetrates fog better than white light, this non-glaring light has proved particularly efficient in foggy and misty weather. In such weather it is always advisable to travel with the antiglare device in operation. In the case of the smaller electrical projector lamps the glare is cut off by shifting the filament lamp out of

Fig. 132a. Electric Motorboat Projector Lamp.

Fig. 132b. Small Electrical Motorboat Projector Lamp.

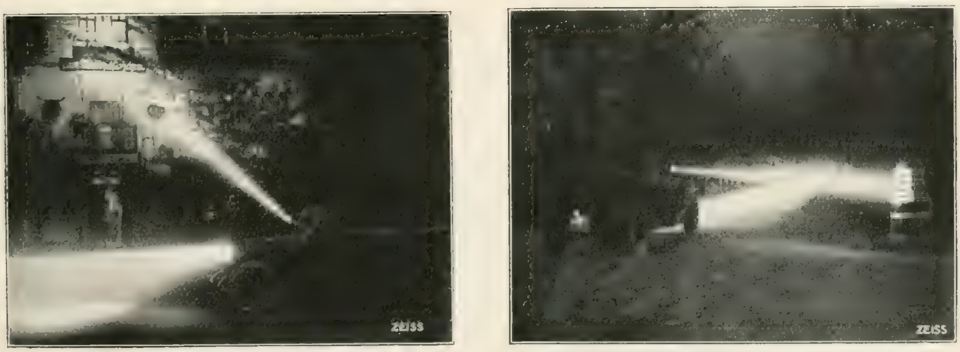


Fig. 133. Electric Spot Lamp in operation.

the principal focus. The intense projector light which results when the combination is in strict optical adjustment is thereby replaced by a shorter beam of a more diffuse light without glare.

Apart from other defects, ordinary projector head lamps do not light up curves in an adequate manner. A sufficient side spread of the light is, however, absolutely essential. This side spread in the case of the Zeiss headlights is increased by a glass front having peculiarly shaped prismatic grooves and ribs.

In addition to large electrical and acetylene projector lamps the Zeiss Works turn out combined projector lamps for acetylene and electrical lighting. Spot lamps are made for flashing from the driver's seat light on objects on either side of the track, such as wayposts, street names, etc. Such a lamp and its uses are illustrated in figs. 131 and 133.

The excellent optical qualities of the Zeiss projector lamps have led to their application to many other purposes, notably for the equipment of motor watercraft (figs. 132a and b), for motor cycles, for fire fighting operations and vehicles employed in these, and so forth. The Auto section, where these illuminating appliances are made at the Zeiss Works, though comparatively young, has developed with great rapidity.

Measuring Instrument Department.

In 1890 Prof. Abbe established a department for the construction of optical measuring instruments, which he placed under the management of Dr. C. Pulfrich. This department has remained small in the matter of its quantitative output when compared with those sections of the establishment which are organised for the mass production of specialised instruments in great demand, such as field glasses and photographic lenses. This need not surprise us, for it is a comparatively small number of persons whose mission it is, not merely to look through telescopes, spectacles, and microscopes, but rather to carry out more or less delicate measurements in connection with these. But, though small in the magnitude of its output, this department has grown within the last three decades all the richer in the range of its products, which are almost exclusively devoted to the problems of scientific research and their practical applications. There is scarcely a physical, chemical, or technological laboratory in any country where scientific methods are in operation that does not possess a Zeiss instrument or one or the other apparatus copied therefrom.

The first question one would naturally ask is, what is it that is required to be measured, and the answer is that this applies to all images and phenomena relating to distant, near, and smallest objects which can be rendered visible in telescopes, microscopes or on the photographic plate and which may appear woith measuring. In the first place, the instruments made in this section include those, largely originated by Abbe, which serve for measuring quantities arising out of the manufacturing operations of the Zeiss workshops themselves, such as the thickness of plates and lenses, the radii of curvatures and focal lengths of simple and composite

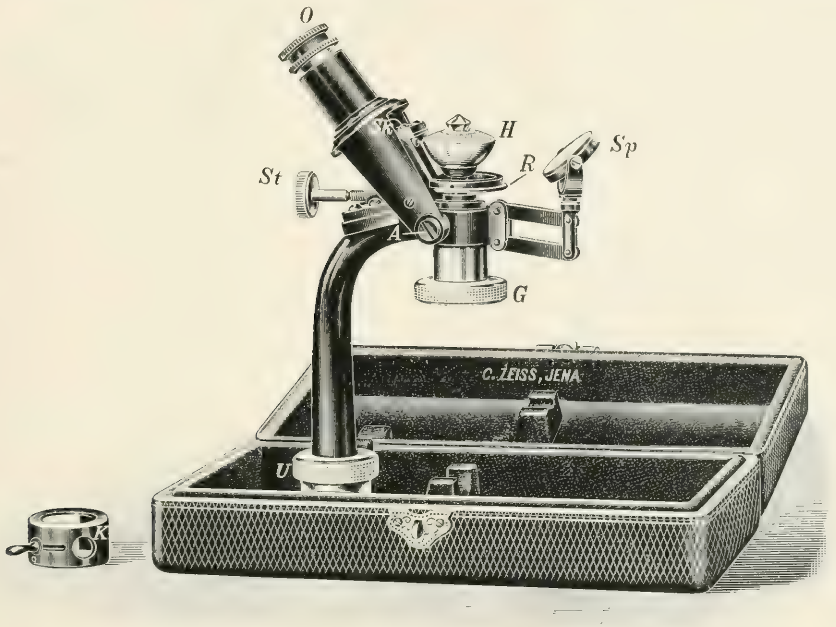


Fig. 134. Crystal Refractometer for Jewellers.

lenses, the refraction and dispersion of the many different kinds of glass and crystals which enter into the construction of optical instruments, the expansion of solid bodies and like purposes. In all these cases it was essential to arrive at these quantities with that degree of precision which, as we know, is characteristic of the entire system which pervades the manufacture at Jena, and which has become a ruling standard for other optical manufacturing establishments all over the world. As evidence of the great value which at the Zeiss Works is attached to unremitting control of all its products by the application of exact measurements it may be

mentioned that within its own walls, but independently of the Measuring Instrument Department, the establishment maintains a large measuring laboratory, where all quantities required to sustain precision in manufacture are determined under scientific direction by specially trained assistants.

All instruments coming within this category, such as *thickness micrometer gauges*, *comparators*, *focometers*, and *spherometers*, *spectrometers* and *refractometers* for solid and liquid substances, the *dilatometer* (fig. 135), which is based upon the

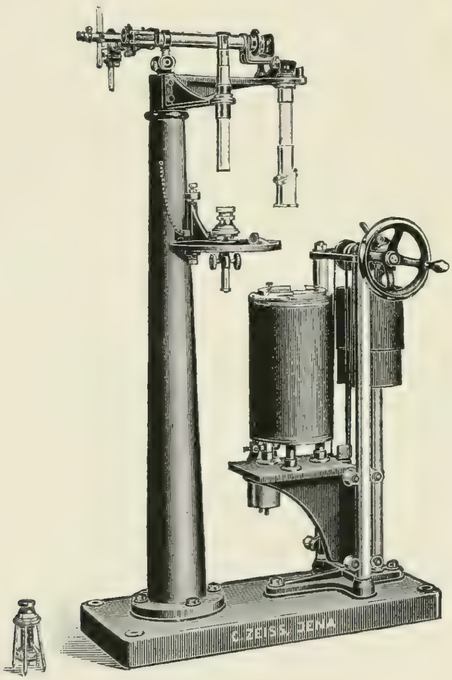


Fig. 135. The Dilatometer.

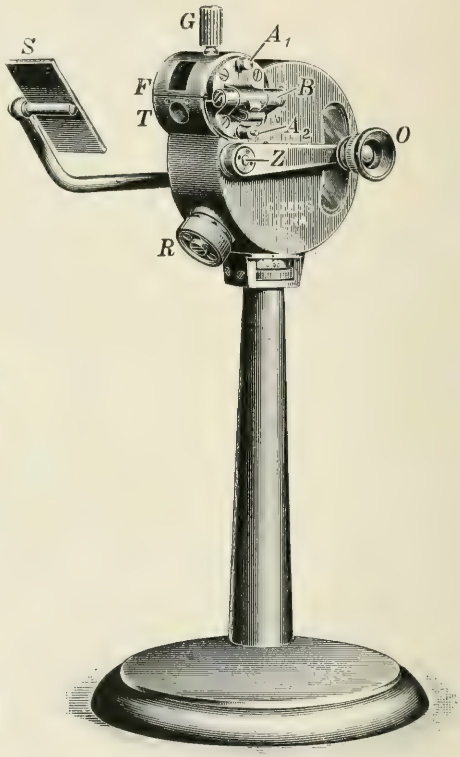


Fig. 136. The Sugar Refractometer.

measurement of wave-lengths, and the *apparatus for testing plane surfaces* and plane-parallel glass plates, after being placed upon the market for the use of other makers, have now also found their way into many other manufacturing establishments. They are also extensively used in universities and other scientific and technical institutions, where they serve many valuable purposes.

In now passing on to the instruments which have originated in the measuring instrument department in the course of years we cannot attempt

to give anything like a complete survey. We will begin with that group of instruments which in the mean time have become indispensible in the equipment of research and testing laboratories.

The *refractometers* in their various specialised forms, viz. the Abbe refractometer, the *butter refractometer* and the *milkfat refractometer* for the examination of oils and fats in the laboratories of food analysts, the *sugar refractometer* (fig. 136) for the service of the sugar, honey and jam industries, the *dipping refractometer* for testing the products of fermentation, such as wine and beer, for the analysis of aqueous solutions and for

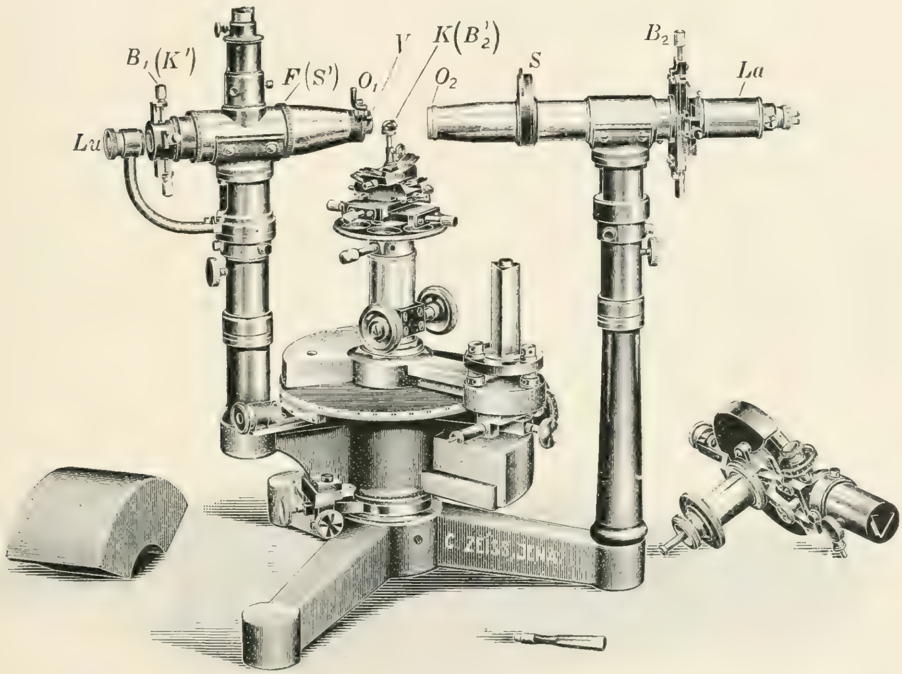


Fig. 137. Crystal Goniometer, with one and two circles.

clinical purposes, the so-called *refractometer for chemists* for determining the chemical constitution of organic bodies, and the *crystal refractometer* for use in mineralogical laboratories and for the practical use of jewellers (fig. 134).

Next we come to the so-called *interferometers* (fig. 138), a species of interference refractometer which goes far beyond the error limit of the refractometer, especially the Haber-Loewe gas interferometer for the

analysis of firedamp and other gases, and also the *water-interferometer* for the analysis of extremely dilute solutions and for use in hospital and veterinary clinics, especially for establishing the presence in the blood serum of the so-called *prophylactic ferments* of Abderhalden, which operate as effective agents against foreign substances in the blood. To instance only one important application of special value in horse breeding, this method of diagnosis, as worked out by Dr. P. Hirsch, affords a means of singling out pregnant mares from others within two weeks after mating. Finally, we may mention the *pocket spectroscope* and the *comparison spectroscopes, colour mixing instruments, autocollimating spectroscopes* and *grating spectroscopes* and *spectrographs* for visible and invisible light.

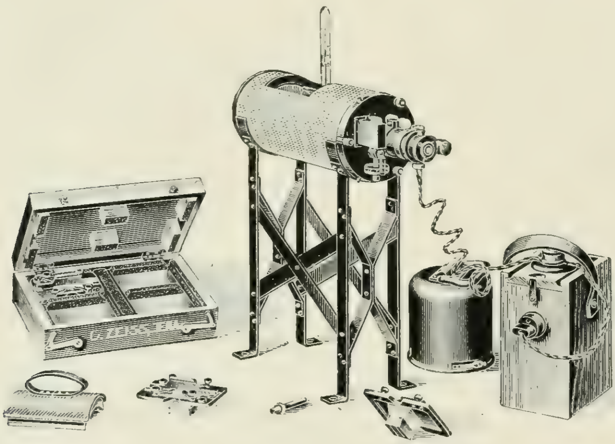


Fig. 138. The Interferometer.

The absorption spectrum of blood furnishes the forensic chemist with evidence of carbon monoxide poisoning. Diseases of the blood may thereby be promptly detected, and metallurgists may draw from the appearance of the emission spectrum valuable conclusions respecting the purity of their furnace products and the presence of this or that admixture. Spectrograms are evaluated in *reading microscopes* and *spectrocomparators,* which have been specially designed for this purpose. A special instrument of this kind shown in fig. 139, which has been designed in accordance with the suggestions of J. Hartmann, is mainly intended for evaluating stellar spectra and hence also for measuring the velocity of stars in the direction of the radius of vision on the basis of Doppler's principle.

Of the *instruments for measuring angles* we may mention amongst others the *hand angle measuring instrument,* the dip-of-the-horizon gauge

for use at sea, the *crystal goniometer* (fig. 137), with one and two circles, and several instruments designed for land surveying and geodetic purposes, a stadiometrical theodolite and an image-measuring theodolite. Among the instruments involving the principles of *interference* mention may be made of Koester's *end measure comparator*, the *interference apparatus* and the Mach *interference refractometers* and instruments for *photographing projectiles in flight.*

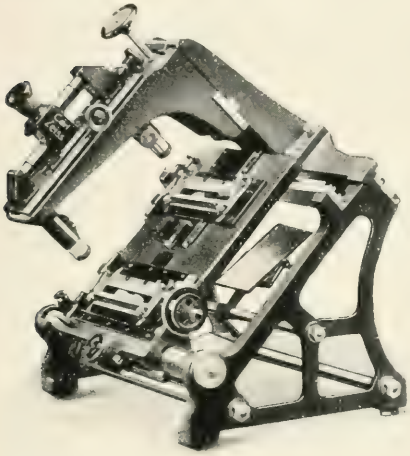


Fig. 139. Spectrocomparator.

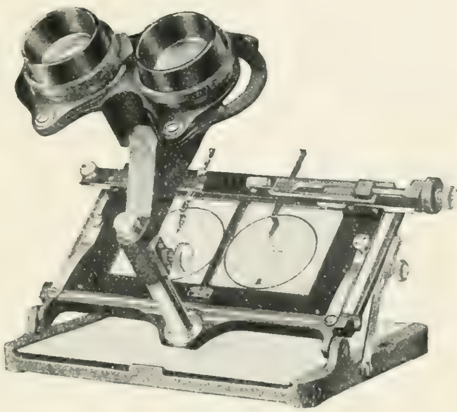


Fig. 139a. Stereoscope.

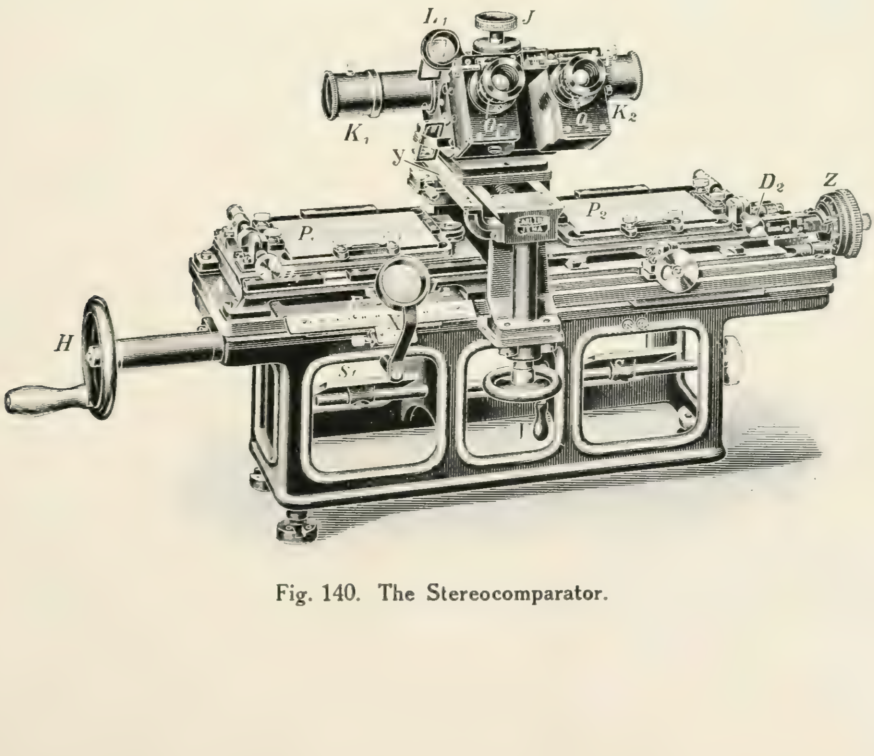


Fig. 140. The Stereocomparator.

In the course of the last twenty-five years this department has applied itself to the *development of the stereoscope* (fig. 139a) *into a measuring instrument.* The stereoscopic range finder, which likewise emanated from this department, has already been referred to in a previous section of this book. In the further development of the stereoscopic method the problem which arose was, not only to be able to measure the distance of the objects seen in the stereoscope, but also to determine their dimensions in length, height, and depth. The instrument devised for this purpose is the *stereo-comparator* shown in fig. 140. This is a stereoscope made up of two microscopes, which serves for viewing plate photographs taken from the two ends of a base line by means of a photo-theodolite specially constructed for this purpose (fig. 141). The length of this base-line requires in each case to be accurately adapted by the photogrammetist to the distance of the object which is to be measured as well as to the required degree of exactness. The method of measurement itself rests upon the use of artificial marks of reference which are slipped from either side into the viewing apparatus and therein create the impression of a solid mark coinciding with the object. This "wandering mark" is so mounted that the operator may guide it at pleasure through the space image of the landscape or along the surface of the object which he wishes to measure. *Stereophotogrammetry* is as yet a young science, but it has long since justified its existence as such and given many proofs of its effective powers of dealing with many and varied problems in geodesy and engineering. Thus, such problems as the plotting of the trajectory of a projectile or the measurement of ocean waves can only be

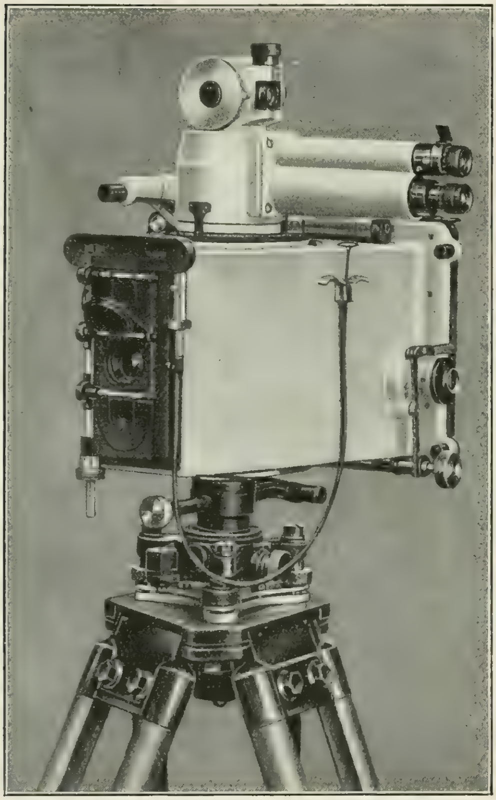


Fig. 141. The Phototheodolite.

solved by its aid. A special advantage of the method springs from the fact that the "wandering mark" can be applied to points of the object which are inaccessible to the topographer's staff bearer. This method has likewise proved practically valuable for measuring near objects, including man and animal. Naked-eye objects and preparations which may not be touched may be directly measured with the aid of the *stereo depth-gauge,* which is a binocular microscope with gauge marks and a micrometric device for raising and lowering it in position.

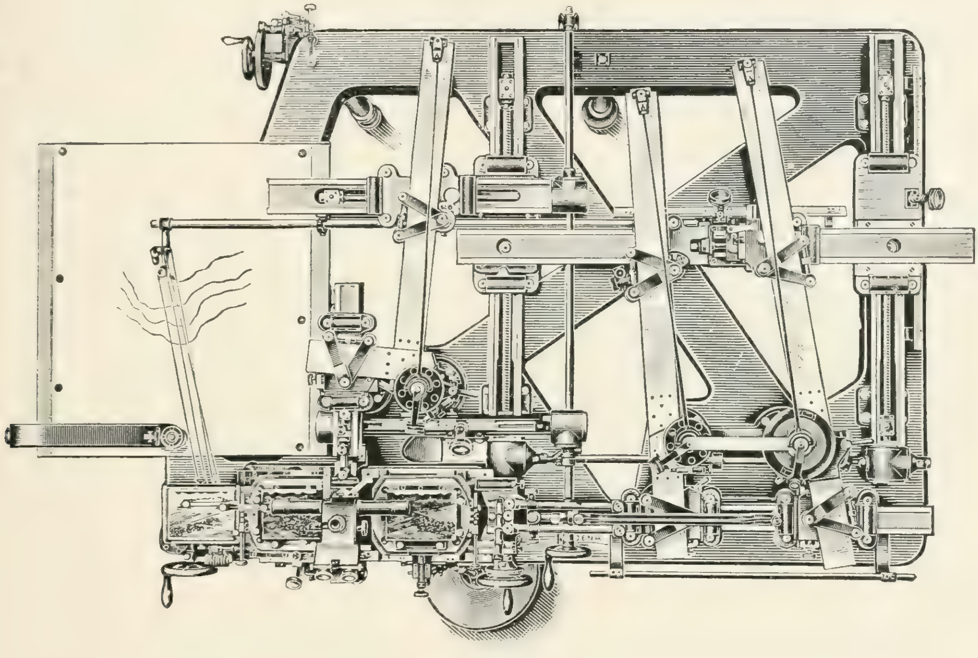


Fig. 142. Stereoautograph.

The resources of stereophotogrammetry have been immensely strengthened by the expansion of the stereocomparator into a *stereoautograph* (fig. 142). In this apparatus, which may be defined as an automatically operating contour drawing machine, the operator, when drawing a contour line (curve of equal elevation), has only to set the instrument to a given level and then conduct the "wandering mark" along the surface features of the landscape picture in the stereoscope. A considerable number of this apparatus have been installed in various offices in Germany as well as in other countries for topographical surveys and for dealing with problems of civil engineering, such as railway construction, water power storage works, canal works, etc.

Quite recently the stereoautomatic method has been extended with excellent success to *geometrical surveys from aircraft,* where it is naturally assumed that a few points, at least three, are known in the component photographs by survey on the ground. The *stereoplanigraph* (fig. 143) is the latest achievement of the Zeiss Works in this province of applied science.

Astronomy provides the stereocomparator with another important field of application. Naturally, the "base-line" for stereoscopically viewing celestial objects is very much longer than that which applies in the case of terrestrial objects. Thus, the stereoscopic survey of the moon demands a base line of as much as 60000 miles, that is about one quarter the distance of the moon from the earth. Again the base lines are very much longer for stereoscopically viewing the stars, in that in their case the path of the sun (about four sun-to-earth distances per year) serves as the base line. The advantage of this stereoscopic method in its application to stellar astronomy lies in the circumstance that, despite the annually increasing length of the base line, the majority of the stars appear to be situated in one plane, from which those stars only appear to stand out which either are relatively near the solar system or which have rapid motions of their own. In stellar astronomy the stereocomparator has again proved a source of tangible success, notably by the work of M. Wolf, of the observatory of Heidelberg, and no less as a means of detecting new planetoids, comets, and variable stars.

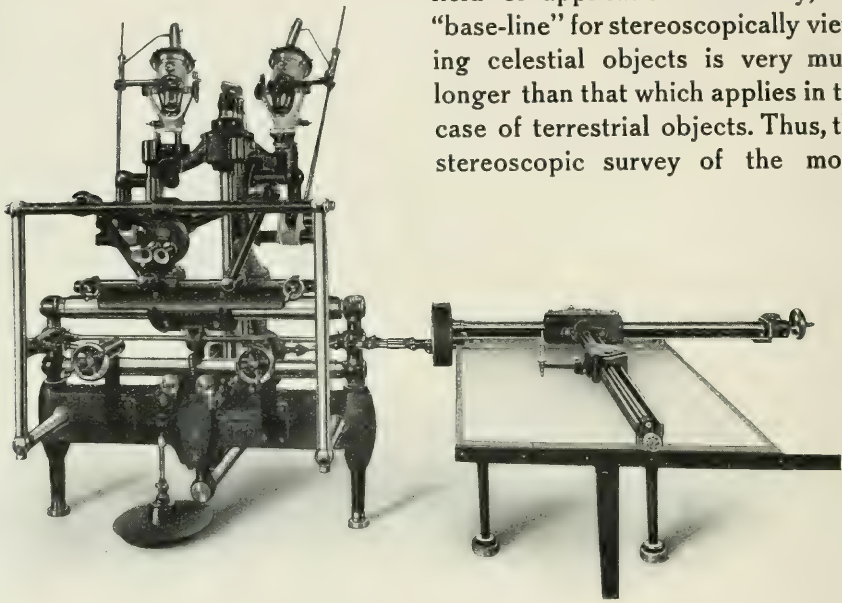


Fig. 143. Stereoplanigraph.

In 1904 Dr. Pulfrich added to the stereocomparator a monocular comparison microscope which is interchangeable with the stereo-microscope and which he described as a *flicker-microscope.* In the eyepiece of this microscope the pictures which are to be compared alternate at short intervals, with the result that those elements which differ on the two plates become at once noticeable by erratic movements or by alternately flashing up and again disappearing (after the manner of flash lights on lightships). This method has likewise met with extensive application in stellar astronomy. A special instrument of this kind has also been constructed for the examination of currency notes and postage stamps.

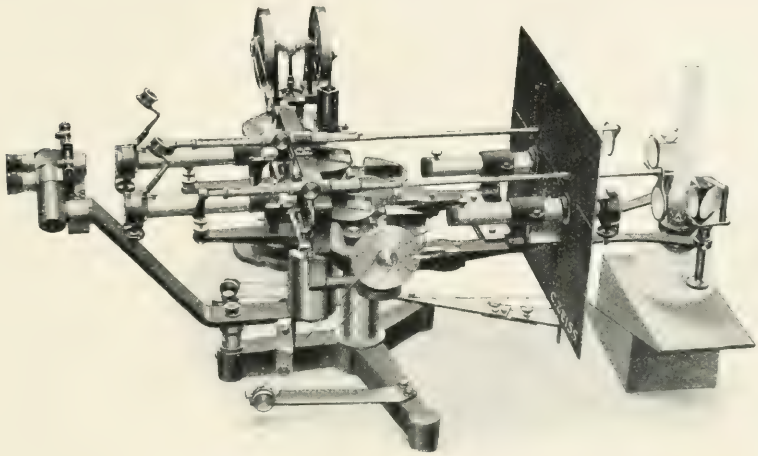


Fig. 144. The Stereo-spectrophotometer.

In the course of the last two years the potential resources of quantitative stereoscopy have been extended to two further branches of applied science, viz. *photometry* and *pyrometry,* which in themselves are in no way related to stereoscopy. Both in the stereocomparator and the stereoautograph a disturbing element has made itself noticeable, but it is only quite recently that its explanation has been forthcoming. It relates to the influence of dissimilar intensities in the two pictures upon the apparent position of the relief image when the pair of photographic plates are set in rapid motion with respect to the measuring mark. In such a case, when the plates are rapidly moved to and fro, the object point is seen to describe a circle about the mark, the direction of the motion being to the right or left according as it is the right or left eye which receives the greater intensity. This phenomenon may be demonstrated in the simplest manner by moving

a vertically held lead pencil to and fro in front of a bright ground and holding a smoked glass in front of one eye. The explanation of this striking phenomenon is to be sought in the fact that the motion of the more brightly illuminated mark reaches the observer's consciousness more rapidly than that of the less brightly illuminated mark. On the occasion of the meeting of physicists at Jena in 1921 Dr. Pulfrich discussed this physically as well as physiologically and psychologically highly interesting subject, and in a monograph published by Julius Springer, of Berlin, he also fully described the *stereophotometer* and the *stereopyrometer*, which in the mean time had been constructed on this principle. A somewhat remarkable feature of this method of observation is that the colour exercises no influence upon the phenomenon. Hence, proceeding from the fundamental conclusion that two colours are identically bright if for either colour the time intervening between the optic stimulus and the sensation are the same, so that the circular motion of the mark reduces to a linear motion, a stereo-spectrophotometer (fig. 144) has been constructed, with the aid of which it has become possible to measure the distribution of the intensity within the spectrum of a source of light, which hitherto could not be accomplished with any of the existing methods of heterochromatic photometry.

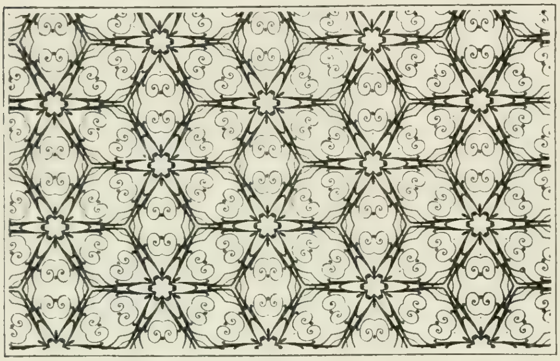


Fig. 145.
Pattern produced with the Photokaleidograph.

We conclude our survey of this interesting section with a brief reference to the *photokaleidograph*, which serves as a means of producing protective designs on papers of value, etc. A pattern produced in this way is reproduced in fig. 145.

The Geodetic Department.

In 1908 the firm decided to take up the manufacture of surveying instruments. A beginning was made with a small level. The design and adjustment of this new instrument were based upon distinctly novel aspects, and little was borrowed from the existing forms of construction. The resulting instruments refuted the then widely accepted notion that the

last word in surveying instruments had been said. As a matter of fact, the levels, such as the one illustrated in fig. 146, are equipped with a number of new devices, whereby both the verification of the instrument and its practical use are greatly facilitated.

A biaxial telescope in conjunction with a reversible bubble provides a means of effecting a complete adjustment within a few minutes. The graduation of the bubble, which was formerly in use, was replaced by a new prism combination, by means of which the bubble can be brought to the centre of its run with far less trouble and much more exactly. The

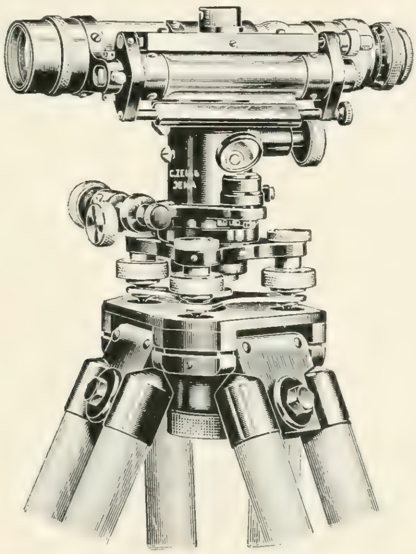


Fig. 146. Small Level with new devices for setting the bubble for coincidence of its ends and for rapidly verifying the instrument from a single station point.

tendency of the axis to turn unevenly, which often gave rise to undesirable interruptions in the older instruments, was overcome by replacing the conical axis by a very accurately ground cylindrical axis. Other primary requirements, such as a watertight and dustproof telescope and similarly protected slow motions and insensitive focussing, have been successfully realised. Also, notable improvements have been achieved in the construction of the stands. It would take us too far were we here to attempt to enumerate the many constructive details which have been introduced and all of which have justified themselves in practice.

Thanks to the peculiar design of the instruments it became possible to accommodate them in cases of unusually small size.

A further important innovation, which has been introduced in the larger models, such as the one illustrated in fig. 147, consists in the optical displacement of the sighting-line parallel to itself within the object space. By the application of this principle an instrument has come into existence which is adapted for the most exacting levelling operations and which unites the advantages of the method of setting the bubble to the centre of its run and that of setting the telescope to a staff line or to the middle between two lines.

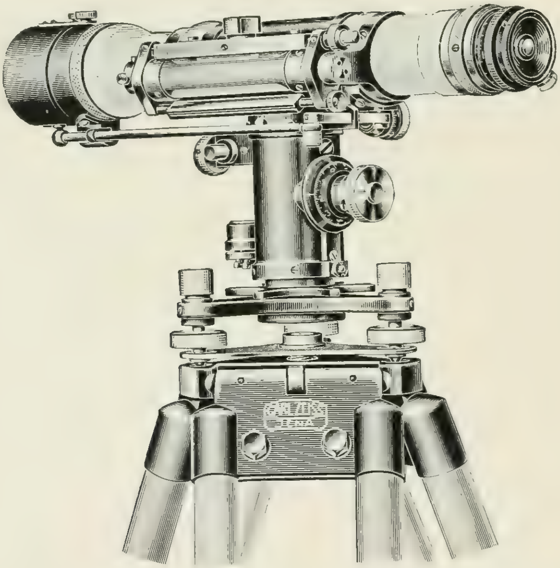


Fig. 147. Large Level with optical variation plate (involving the principle of the parallel optical displacement of the sighting-line).

A tacheometer level with tangent screw and horizontal circle has been designed for the rapid surveys of gently undulating ground.

The new Zeiss theodolite shown in fig. 148 likewise exhibits fundamentally new points. The principle, however, on which the circles are read differs entirely from the established method. Attempts had already been made, it is true, to unite the two diametrically opposite microscopes into a single one, but it still remained necessary to take two readings and to form their arithmetical mean. In the new method and the arrangement for

its application a single reading furnishes the required mean, and this applies to the horizontal as well as the vertical circle. Moreover, both circles are read in one and the same eyepiece, which is situated at the side of the telescope eyepiece and participates in the transit motion of the telescope. The micrometer screw is likewise common to both, and the drum is read in the eyepiece. Readings are thus taken without movement of the head and without any manipulative changes. Fig. 149 shows the scale

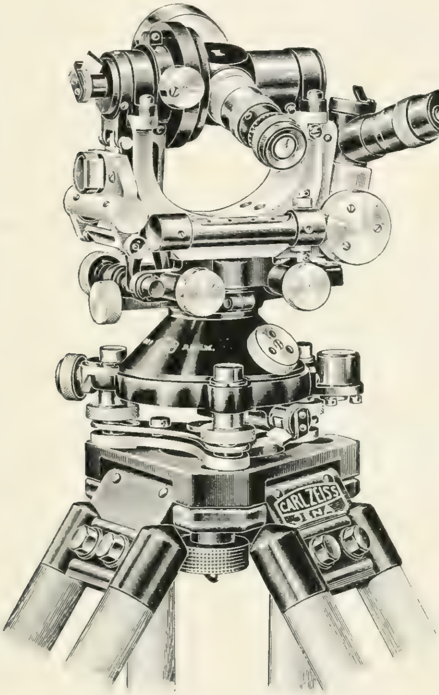


Fig. 148.
Zeiss Theodolite, Model No. I.

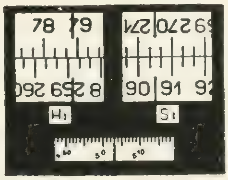


Fig. 149.

portions as they appear in the reading eyepiece when the division lines in the vertical circle have been brought into coincidence with the aid of the micrometer screw. In the case instanced the vertical angle reads $90^{0}\ 35'\ 3''$. It is no small advantage that the readings depend solely upon a few parts which are securely mounted within a protecting enclosure. In addition, the theodolite is remarkably compact, small in size, and light in weight. The telescope, though only 137 mm. (5·4 inch.) long, has an aperture of 30 mm. (1·2 inch).

Precision levelling staves with "Invar" inlay, prisms for offsetting at right angles, as well as several other instruments and accessories for surveying purposes are likewise manufactured within the scope of this department.

Micrometer Tool Department.

(For the manufacture of gauge instruments of high precision.)

At the end of the war, when a large proportion of the scope of manufacture became inoperative, it became necessary to find fresh outlets. Gauges for technical operations were selected as appropriate because they were closely allied to the then established range of manufacture, to say nothing of the fact that the firm had already for many long years been

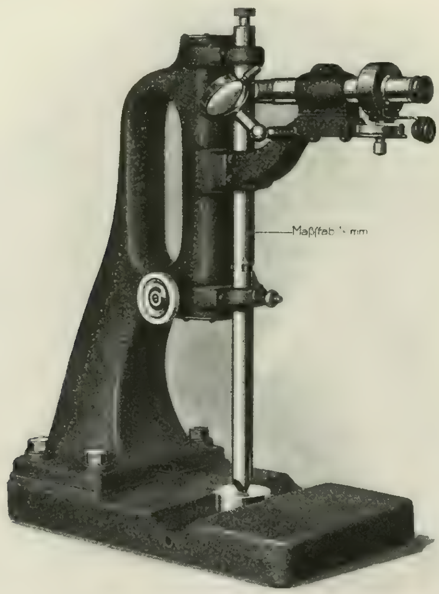


Fig. 150. The Abbe Depth Micrometer Gauge.

in the habit of producing implements and instruments of this class for its own use. Moreover, several special instruments serving for accurate gauging in the course of manufacture had already been placed upon the market, such as the Abbe thickness micrometer (fig. 150) and the comparators. Finally, it could not fail to present itself as a welcome supplement to the

then existing manufacture to produce implements such as serve the everyday requirements of the industry, whilst a large portion of the other Zeiss products were destined for scientific uses or represented objects essentially of a kind which added to the amenities of life. Many of the gauge tools which were in daily use in the workshops and stood in good repute had been obtained from abroad before the war, but in the mean time had receded beyond the reach of payment. These very instruments were devised in the form of purely mechanical measuring appliances. It seemed a tempting proposition to apply the many possibilities of optical devices for the further development of precision gauges.

In order to open manufacture with the least possible delay, a few implements were selected the construction of which had in the main been fully established since years, but an immediate endeavour was made to introduce improvements in design and exactness over the available prototypes. In this category are to be included more especially the so-called *screw micrometer gauges* (fig. 151). In their case optics could be made to play a part in so far only as it entered into the control of the manufacturing process and of the materials used. With the aid of optical devices, however, it became practicable to enhance the precision of the screw to such an extent that the pitch error did not exceed 3/1000 mm. at any point and that the difference between any two arbitrarily selected points always gave precisely the same correct reading. The contact surfaces were tested with the aid of the interference method (based upon the observation of Fizeau striae), which had been in use as an aid to certain optical processes of manufacture. The two contact surfaces, it should be noted, are required in all rotary positions of the micrometer screw to be strictly parallel within 2/1000 mm. to satisfy the Zeiss standard and, either taken individually, is to all intents and purposes optically plane since no point thereon is permitted to depart by more than 1/1000 mm. from the ideal plane. This was achieved not only by equipping the workshops with the requisite apparatus for controlling every element during the process of manufacture but also by the introduction of a rigorous system of tests to be applied to the finished article. The conditions which each finished article has to fulfil are laid down in delivery schedules, and not a single

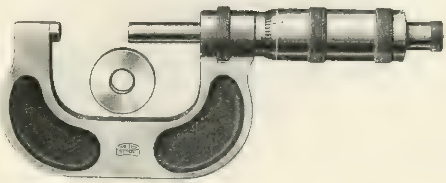
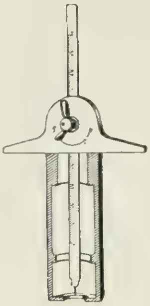


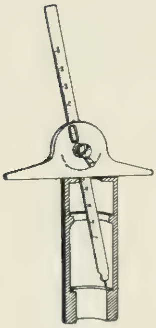
Fig. 151. Screw Micrometer Gauge.

article may be released which does not conform in every respect to these stringent requirements.

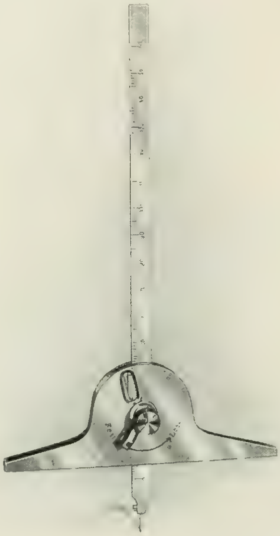
Other mechanical gauge tools were likewise found to be capable of improvement and further development in the matter of their external form and handiness. These include *depth gauges,* which shortly after appeared in a new form as *oblique depth gauges.* The latter serve for gauging recesses and small collars in tubes or bored holes; the



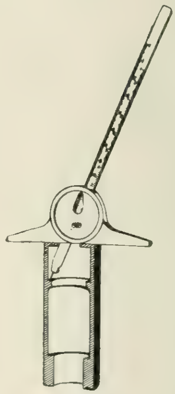
Position No. 1.



Position No. 2.



Figs. 152 to 155. Adjustable Depth Gauge.



Position No. 3.

device being so arranged that, though the stem occupies a slanting position in its slide collar, the gauge nevertheless reads vertical distances to the datum surface. This idea was carried a step further in the *adjustable depth gauge* which is available for vertical measurements as well as for oblique measurements at two different angles (figs. 152 to 155). In any of these positions that one of the three scales only can be read which according to the angular position of the pointer bar gives the vertical depth. Mechanical improvements have likewise been achieved in the construction of *inside micrometer gauges.* These serve for measuring bores of fairly large size and consist of a micrometer screw and standard *end-measuring gauge pieces* of various lengths. These are spherical-ended and accurately ground to the prescribed lengths. They are contained within tubular shells and are held together by a uniform spring pressure when these shells are screwed

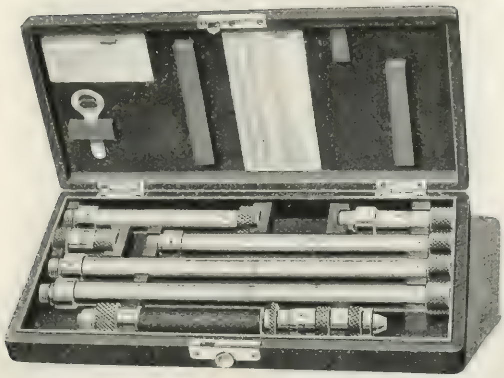


Fig. 156. Set of Inside Micrometer Gauges (in front the micrometer screw).

together. In consequence of this arrangement the resulting gauge length is not affected by the degree of tightness applied to the screw joint (fig. 156).

There was another species of gauge instruments which presented particularly attractive problems to the designer. These were the gauges of the indicator type. In these instruments a feeler, mostly under spring pressure, lays itself against the object and its small movement is magnified by mechanical means and transmitted to a pointer which plays over a scale. In this connection an opportunity was afforded of improving the transmission mechanism. Tests which were applied by measurements mechanically repeated a million times gave convincing proofs of the enduring qualities of the affected parts by the invariable amount of the index motion. This class of indicator gauges includes a *micrometer test lever* with a range of 0·2 mm. and capable of reading accurately to 0·005 mm., the *Zeiss Micrometer Indicator* (fig. 157) with a range of 0·1 mm. and giving readings exact to 0·005 mm.; finally the *Dial Indicator Gauges* and *movable limit gauges (Passometers* and *Passimeters).*

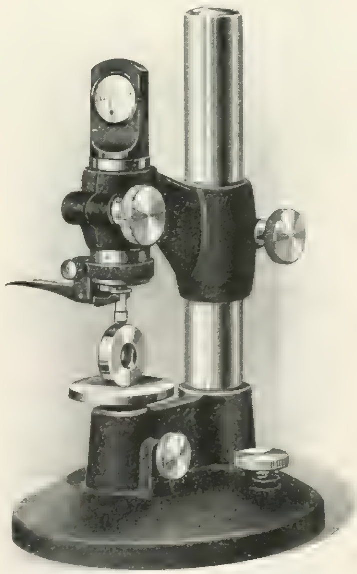


Fig. 157. The Zeiss Micrometer Indicator with stand.

The *Zeiss Dial Indicator Gauge* conforms externally to well-known test indicators but in its internal arrangements it was found necessary to depart very considerably from these in the endeavour to secure greater precision. It was chiefly used, mounted on stands and rails, for verifying the true running of transmission shafting, for setting motion bars and guide plates parallel to one another, etc. Since, however, it was found practicable to realise an adequate degree of exactness within a range of 10 mm.,

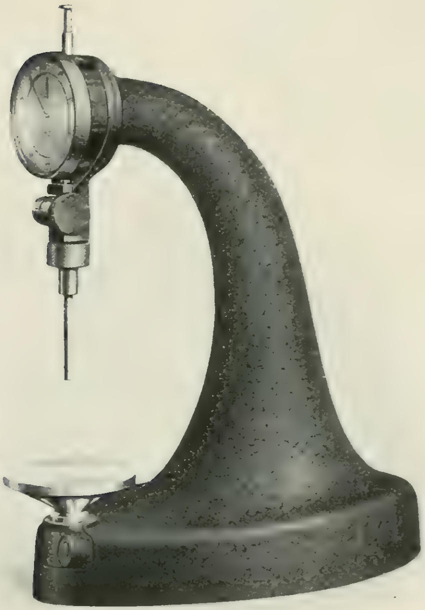


Fig. 158. Dial Thickness Gauge with interchangeable gauge bars of fixed lengths (0 to 90 mm.).

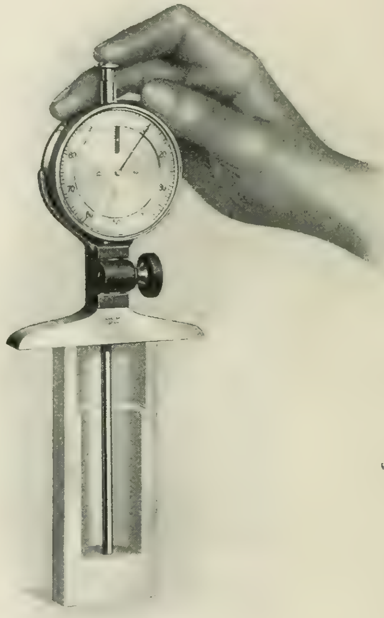


Fig. 159. Dial Depth Indicator with interchangeable gauge bars of fixed lengths.

its resources were developed by mounting it in suitable stands for use as thickness indicators and dial depth indicators, as shown in figs. 158 and 159. The measuring range of these instruments can be extended and restricted by graded contact pins.

A practically new departure was inaugurated by the introduction of *movable limit gauges*. The mass production of interchangeable parts is dominated in these days by the use of fixed limit gauges of the plug-and-ring or jaw type. Thus, a shaft is supposed to have the proper diameter

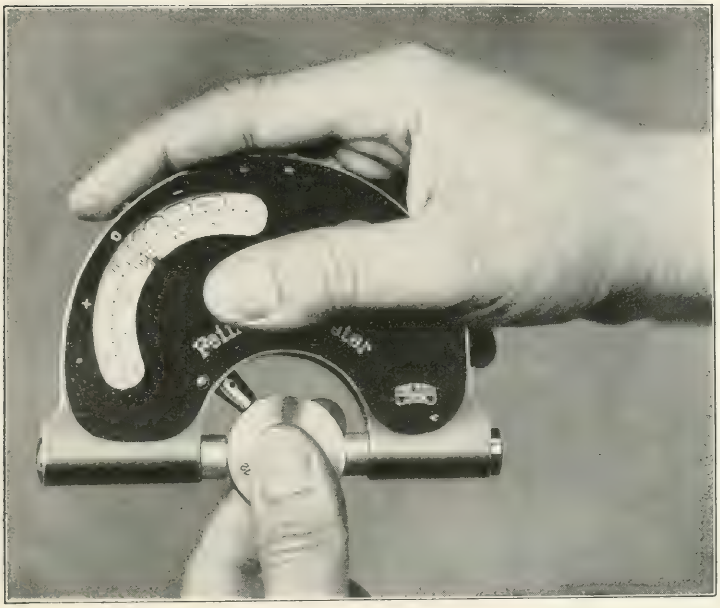


Fig. 160. A Passometer.

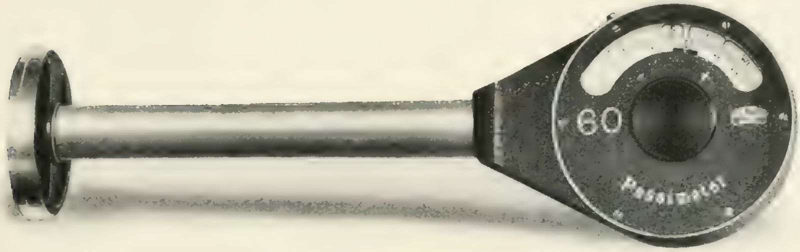


Fig. 161. A Passimeter.

when a certain jaw gauge can be just made to "go on", while another given gauge will "not go on". As many gauges are therefore needed as there are different diameters, and these gauges are differently formed according as they are required to measure inside or outside diameters. Moreover, they differ according to the degree of tolerance, which in its turn is governed by several conditions. This requisite battery of gauges may be greatly reduced by the introduction of gauges having one of the contact jaws or ends movable and provided with a device by which the deviation from a given standard value can be read off. An additional advantage arises in this case from the fact that the gauge shows, not only that there is an excess of material, but also the amount of the excess to

be removed. An important problem which incidentally arose was to find handy workshop forms for these gauges. The *Passometer* (fig. 160) was thus evolved as a movable outside gauge, which has a kidney-shaped box containing the lever and indicator mechanism. The *Passimeter* (fig. 161),

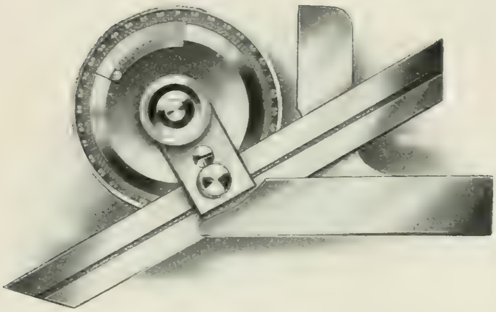


Fig. 162. Universal Bevel Protractor.

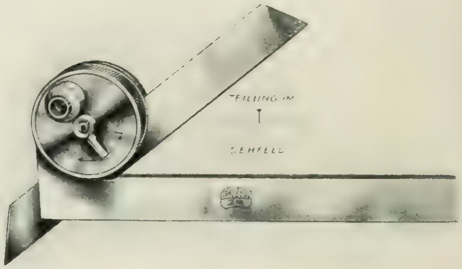


Fig. 163. Universal Optical Protractor.

which forms the inside gauge, has spherical contact ends in order to satisfy the further condition that the readings of a cylinder diameter should be independent of the precise manner in which the gauge is applied with respect to the axis of the cylinder.

In some cases the application of optical devices has led to further developments in gauge tools. After having been made for some time in the original form in which the bevel protractors came from the United States, as shown in fig. 162, it was developed into a *universal optical protractor* for use for the same range of purposes for which it had been originally designed. In this optical modification the scale divisions, though much finer than in the purely mechanical gauge, can be easily read, being ruled upon a transparent glass plate and viewed through a magnifier. Thanks to the magnification the reading can be taken with sufficient ease to render a vernier superfluous (fig. 163).

While thus, on the one hand, an existing tool was improved by the addition of an optical element, certain well established optical instruments were rendered available for use in the workshop by giving them a convenient form well adapted for use in the workshop.

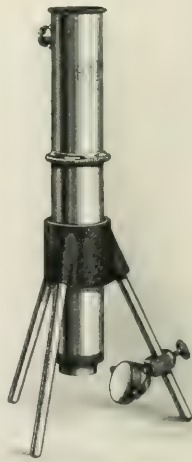


Fig. 164.
Simple Measuring Microscope with scale contained in the eyepiece.

The microscope has for many years played a very subordinate part in mechanical workshops. In its simplest form, that of the measuring or so-called *reading microscope,* such as the one shown in fig. 164, which has in its eyepiece a linear scale, it has been used with great advantage for viewing and measuring small parts. Slide carriage reading microscopes (fig. 165) have likewise been in use for measuring the length of large pieces and especially for measuring ball impressions produced by the Brinell test for ascertaining the degree of hardness of machine parts in

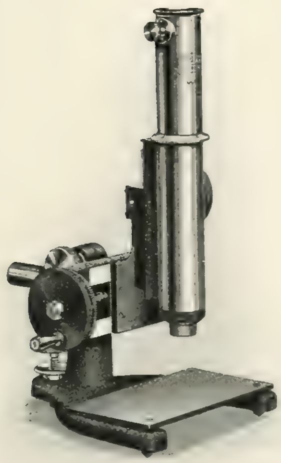


Fig. 165.
Slide Carriage Reading Microscope.

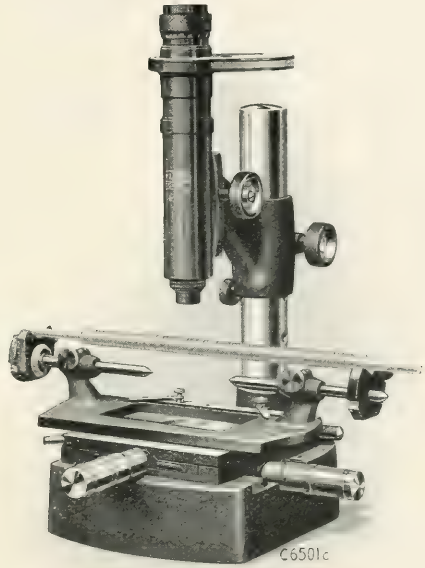


Fig. 166. Workshop Measuring Microscope with revolver graticule diaphragm.

the process of making. It was, however, only after the construction of the *workshop measuring microscope* (fig. 166) that the extraordinary wealth of uses of this microscope in many workshop operations became apparent. Externally already the microscope presents an appearance which entirely departs from the existing designs. This is not surprising when it is borne in mind that these workshop microscopes serve entirely different purposes. The microscope can be clamped at various heights but moves up and down in such a manner that it does not turn. Under it it has a stage which can be made to travel in two directions by two micrometer screws, which

are completely enclosed externally. The majority of workshop measurements may be readily made with this microscope, such as the distance between two lines, graduations, drill gauges, ball tests, tooth racks, etc. It has the special advantage that it may be used for measuring angles. It is made in two forms, which differ by the arrangement of the eyepieces. The "universal eyepiece" exhibits two double graticules, which may be turned with respect to one another and thereby furnish a means of measuring angles, for example in lathe tools, milling tools, gear tooth templates, and

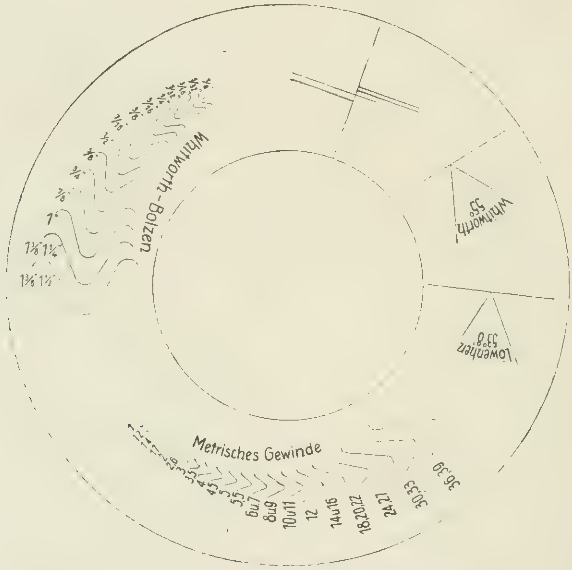


Fig. 167. Revolver Graticule and Profile Disk.

especially also the thread angles of screws. For this latter purpose there is, however, another arrangement, which has the advantage of being very simple in use, viz. the "revolving graticule and profile plate" shown in fig. 167. By operating the revolver any of the standard screw thread profiles may be brought into the field of view and into coincidence with the thread profile which is to be checked. In this way, apart from the thread angle, the correct symmetrical position of the thread faces, the depth of the thread, and the chamfer may be verified. The micrometer screws of this microscope have a measuring range of 25 mm. (1 inch), but there is a *large workshop measuring microscope,* which is similar to the smaller model but available for other purposes, such as taper measurements, and which has a range of 50 mm. (2 inch.) transversely and 200 mm. (8 inch.) longitudinally.

The *Optimeter* illustrated in fig. 168 is an instrument which embodies the application for workshop practice of an old and well-known measuring principle, viz. Poggendorf's mirror and scale reading method, which has been used during the last hundred years in connection with numerous physical measurements. In this instrument the scale lies in the principal focal plane of the telescope. The rays proceeding from it are rendered parallel by the objective and are reflected back by a revolving mirror so as to superimpose an image of the scale upon the latter itself in the principal focal plane. The rotary displacement of the mirror is produced by small movements of a pin made to move in a straight line. The graduation in the field of view reads directly displacements of $^1/_{1000}$ mm. The fifth part of each of these divisions can be read off and also measured. The accessories are adapted for workshop practice and the special purposes of the instrument, especially for rapidly gauging balls, cylinders, fixed gauges, etc. When moderately large cylinders, such as standard ring gauges, are to be measured the optimeter tube is set horizontally opposite a movable stop. The piece which is to be gauged lies on a slide carriage which moves very freely along the gauge line of the optimeter. This arrangement is shown in fig. 169.

In all cases the optimeter serves for measuring small *differences* of length. Since modern practice has largely replaced the graduated rule by limit gauges, measurements of length amount in the main to

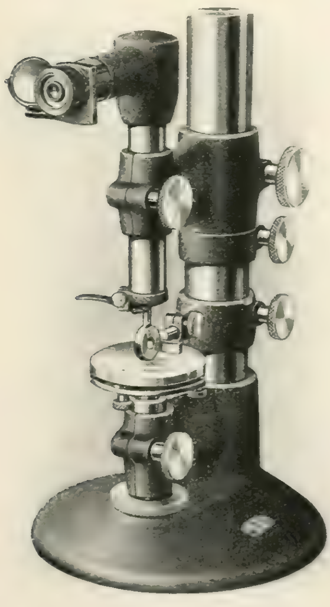


Fig. 168. The Optimeter.

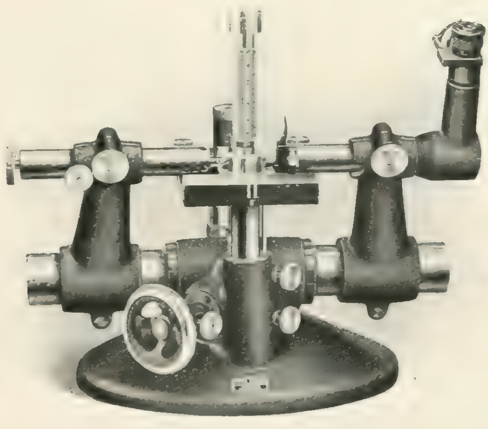


Fig. 169. Optimeter on horizontal stand.

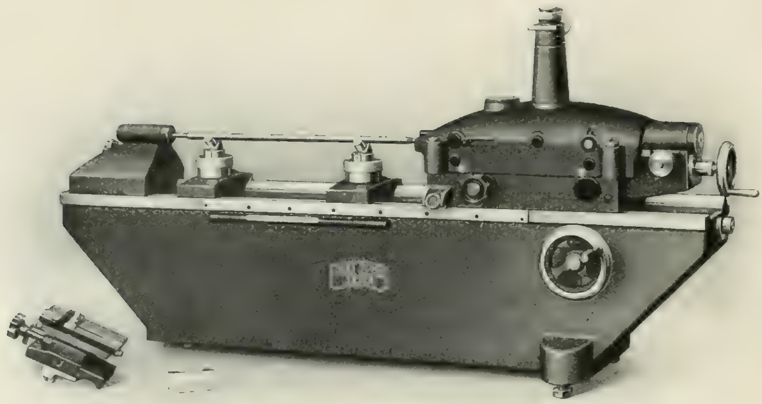


Fig. 170. Outside Measuring Machine.

comparisons with such limit gauges much in the sense that in the workshop absolute measurements are now almost entirely replaced by comparisons with some standard piece or gauge.

The graduated scale is, however, still in its proper place where the use of standard gauges is impracticable. Use of it is made, to give an instance, in the case of Abbe's classical *thickness micrometer gauge,* which was the first instrument to embody a practical application of the principle

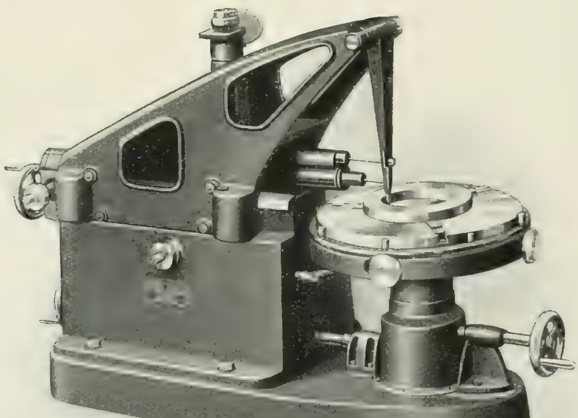


Fig. 171. Inside Measuring Machine.

of the comparator propounded by Abbe to the effect that the linear section which is to measured should be the exact continuation of the scale.

The *outside measuring machine* shown in fig. 170 combines the fundamental peculiarities of the thickness micrometer gauge with those of the optimeter. The measured length results accordingly as a sum made up as follows:

1. The length of a standard plug, bar or rod, as furnished by a set advancing in stages of 50 mm.;
2. That portion of the remainder which can be read to the last complete $1/10$ mm. on a scale 50 mm. long with the aid of a microscope;
3. The finally remaining fraction of $1/10$ mm. which can be read down to 0·0002 mm. by means of a device constructed on the lines of the optimeter, both the fractional remainder and the scale appearing in the field of view.

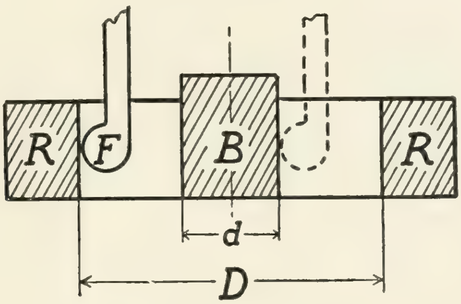


Fig. 172. Principle of the Inside Measuring Machine. The cylindrical ring R can be centred with the aid of fine screws upon a very smoothly running axis, and the contact lever or feeler F is laid against it. Next, a reading is taken of the displacement v of the feeler carrier required to place it in contact (in the same sense as before) with the cylindrical bolt B, which is likewise required to be carefully centred. Let d be the known diameter of the bolt, then the inside diameter D of the ring will be $D = 2v - d$.

The *inside measuring machine* is similar in design. It is, however, the first machine by which an inside measurement has been directly referred to an available outside measurement. The actual principle of the method will be gathered from fig. 172 and the explanation given thereunder.

In another outside measuring machine introduced more recently for measuring lengths ranging from $1/2$ to 6 metres (18 inch. to 20 feet) the use of end-measuring gauges has been entirely dispensed with and replaced by a scale proceeding in intervals of 10 cm. At any point these sections may be continued at their exact terminal line by the *optical* attachment of a scale of 100 mm. divided into tenths of a millimetre, the remainder of

the piece or rod to be measured being again ascertained to 0·0002 mm. with the aid of the optimeter. On the Abbe principle of the comparator, strictly applied, the scale should be in the exact continuation of the length which is to be measured, so that in order to measure a rod 20 feet long the machine ought to be 40 feet long. To circumvent the consequences of a strict application of this principle the scale is arranged under the plane of the object to be measured, but the errors which ordinarily would arise from this departure from the strict principle are fundamentally eliminated by a new optical arrangement. The 10 cm. scale divisions and the 0·1 mm. divisions are both read off in *one and the same* microscope, the lines of the wider divisions serving as indices for the reading of the fine divisions.

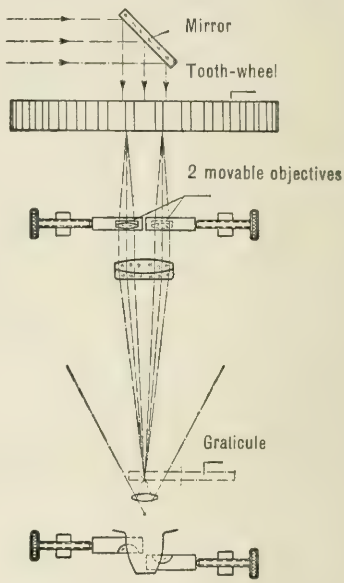


Fig. 173. Diagram of the Tooth Wheel Tester.

Certain frequently recurring machine parts present particularly fruitful problems for the application of ingenious measuring devices. These include such important elements as tooth wheels and screw threads. In the case of tooth wheels both the profile and the pitch are matters requiring critical control. For both purposes instruments have already been devised or are in course of completion. The pitch is controlled by being transferred in a simple manner to a circular disk in the form of a divided pitch line. This disk is placed upon the *testing apparatus for circular graduations,* it is then centred and tested with respect to the uniformity of the divisions with

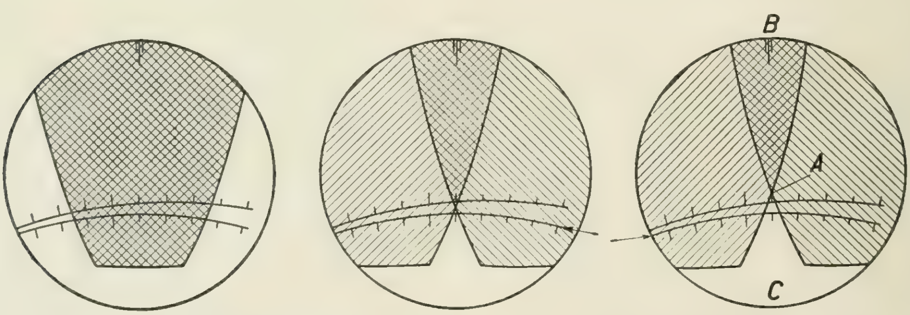


Fig. 174. Field of view of the tooth-wheel testing apparatus.

the aid of two microscopes, one of which has in its eyepiece a movable graticule. The *tooth-wheel testing apparatus* embodies likewise the application of an optical principle. In it use is made of a double-image microscope which forms two laterally displaced images of one and the same field of view. The amount of this displacement can be measured micrometrically (see fig. 173), and two different points of the tooth-

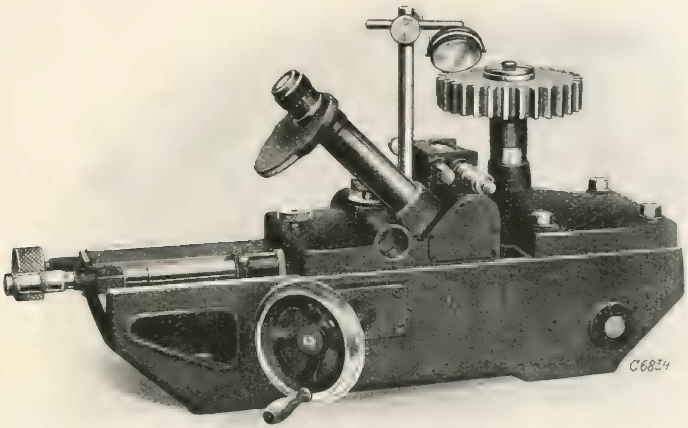


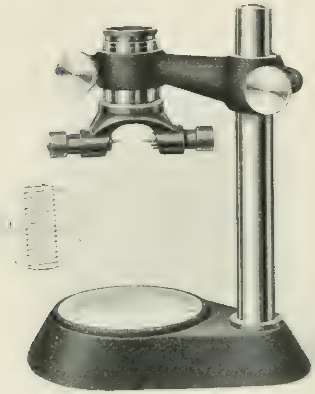
Fig. 175. Tooth-wheel Testing Apparatus.

wheel may thereby be made to coincide. These points may either lie on the two faces of a tooth or on two faces bounding a gap. Thus, the coincidence of the two images, as indicated in fig. 174 a, will give rise to the appearance shown in fig. 174 b. The position of the "dark area" furnishes a measure of the thickness of the tooth and may, for example, be judged by the position of the apex of the dark figure. Fig. 174 c illustrates

Fig. 176. Screw Micrometer Gauge for screw threads with interchangeable contact pieces.

a case where the thickness of the tooth exceeds the given tolerance. By the rotation of the hand wheel all the teeth and all the gaps of a wheel may be compared. Thanks to the ease and rapidity with which the measurements can be made the instrument, as shown in fig. 175, has promptly found its way into the workshop.

In the case of screw threads it is a matter of measuring the pitch and the diameter of the thread (as well as the outside diameter and the core) and the thread angle. The thread diameter



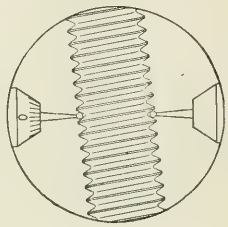


Fig. 177. Optical Screw Thread Calipers. Fig. 178.

is most easily determined with the aid of the *screw thread micrometer*, which is a micrometer screw gauge having its flat contact faces replaced by two pieces with inside and outside vees fitting the screw profile and interchangeable in the latest models. The method of gauging screw threads with the ordinary micrometer screw gauge in conjunction with *wires* placed

Fig. 179. Profile Magnifier set up on the lathe work.

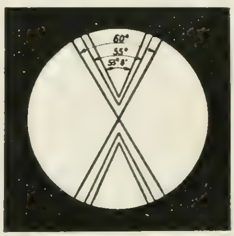


Fig. 180. Field of view of the Profile Magnifier.

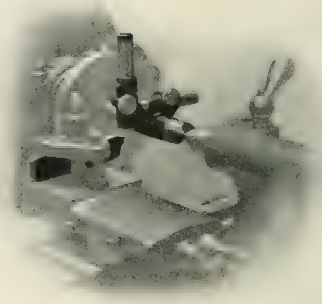


Fig. 181. Profile Magnifier between lathe centres.

into the threads has likewise been applied in Zeiss gauges. A simple comparison apparatus for the same purpose takes the form of the *optical screw thread calipers* shown in fig. 177. The appearance, under the magnifier, of the screw and the feelers is shown in fig. 178.

It has already been mentioned that the *workshop measuring microscope* may be used with advantage for the measurement screws. The two motions of the stage lend themselves both for measuring the thread diameters (outside and core) and for gauging the pitch. This microscope is provided with a correctly set carrier, which ensures that the screw thread may be

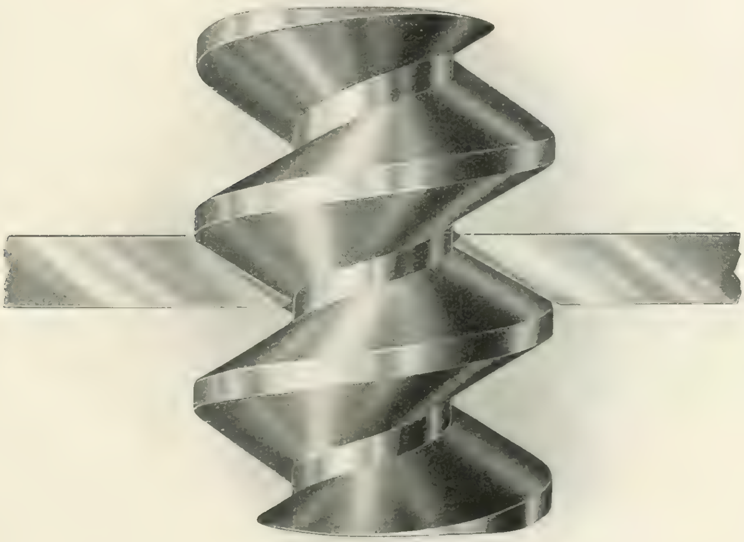


Fig. 182. Showing method of measuring the diameter of the screw thread.

made to occupy a correct position with respect to the graticule lines of the universal eyepiece or the screw profiles on the revolver eyepiece. This carrier receives the screw which is to be tested either between centre points or within prismatic contact pieces. Thus, a comparison of the thread profile with the corresponding profile on the graticule and profile plate (fig. 167) affords a means, not only of verifying the thread with respect to its correct dimensions, but likewise as to the symmetry of its position

with reference to the axis of the screw thread, that is, for ascertaining as to whether the thread runs without skew.

In order to obviate the formation of a skew thread in the making a little instrument described a *Profile Magnifier* has been devised. This is adapted for viewing the turning tool and for comparing its profile angle and its position with the profile drawn on a glass plate contained in the magnifier. This drawn profile itself is adjusted in position to the axis of the lathe by mounting the magnifier on the work or between the lathe centres (figs. 179 to 181).

A simple and rapid comparison of the pitch and the diameter of the screw thread with a screw gauge may be made with the aid of a *dial screw thread caliper.*

More refined devices, however, are needed for the exact verification of the dimensional data of screw threads, especially in the production of exact screw gauges. A critical examination of the screw surfaces of which screw threads are made up shows that the ordinary optical methods devised for the measurement of screw threads do not furnish an unqualified cross-section through the axis of the screw thread, as will be seen from fig. 182. On the contrary, they furnish a projection which deviates from the desired sectional figure. The *Screw Thread Measuring Microscope* shown in fig. 183 obviates this error by the use of two knife edges situated in the plane of the axis and placed in contact with the profiles of two diametrically opposite threads, where they produce fine luminous slits. The latter serve in the place of the thread profiles themselves, to measure the thread diameter as well as the thread angle, as regards size and pitch. The screw thread measuring microscope is made in two patterns. The smaller one of these serves for the measurement of screws up to 25 mm., the larger up to 60 mm. outside diameter. By means of a longitudinal slide carriage the screw may be displaced under the microscope by means of an exact standard

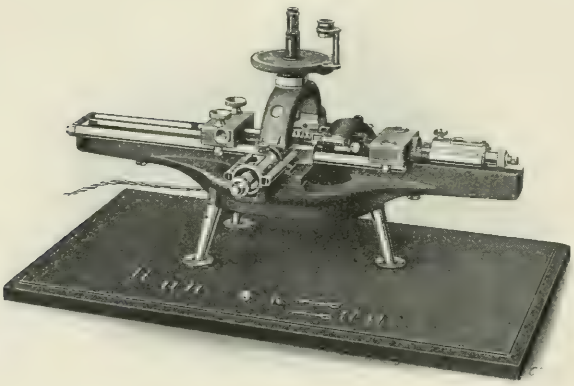


Fig. 183. Screw Thread Measuring Microscopes.

screw for the purpose of ascertaining the pitch. A transverse slide carriage serves to displace the microscope above the stationary work piece for determining the diameters. The thread angle is measured by the rotation of an index-line in the microscope. Screw Measuring Comparators are made for still larger diameters. Of these one is available for screws ranging in diameters from 0 to 90 mm., the other for screws ranging from 0 to 150 mm. in diameter. In these the place of a standard screw is taken by graduated scales, which are read by means of microscopes. These are the most exact of modern means extant for the measurement of screw threads of all dimensions (fig. 184).

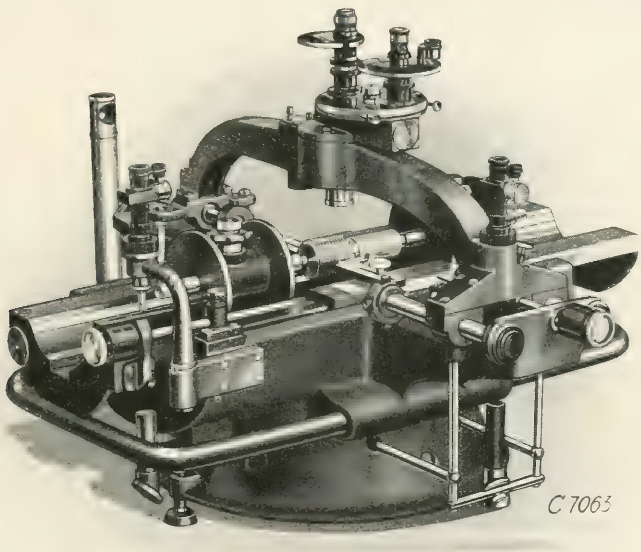


Fig. 184. Screw Thread Measuring Comparator.

For *verifying the pitch of leading screws* a special instrument has been devised to satisfy practical workshop requirements, which centres in a rapid and reliable determination of the traversing motion of the nut on the leading screw.

The application of optics to devices for testing tools promises to cover a very wide range of possibilities. An example is furnished by a problem of great economic importance, viz. the *control of twist drills.* In

their case it is important that the cutting edges should be symmetrical with respect to the cylindrical body of the drill. The combination of a magnifier with an appropriate drill holder provides a means of checking this condition at a glance (figs. 185 and 186).

The modern development of the system of standardisation has rendered it necessary to introduce a degree of precision in the construction of measuring instruments and gauges which formerly was observed only

Fig. 185. Twist Drill Magnifier.

occasionally in the construction of physical instruments. Obviously, where the parts which are to be interchangeable are required not to differ by more than the hundreth part of a millimetre or a fraction thereof, the measuring implements must necessarily be endowed with a still higher degree of accuracy. Nowadays measuring tools are mostly tested by fixed gauges, notably in the form of limit gauges, as first introduced into technical

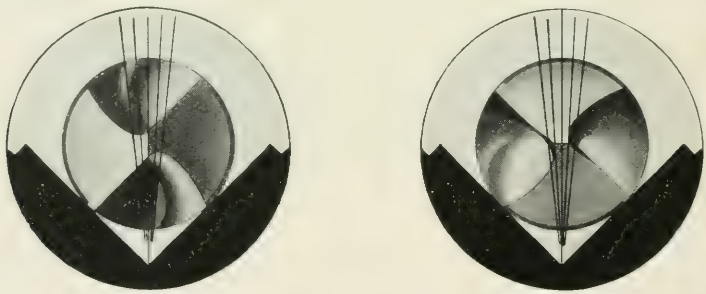


Fig. 186. Field of view of the twist drill magnifier.

practice by Johannson and as now supplied by many other tool-making establishments. In its turn the exactness of these sets of gauges requires to be verified within fractions of a thousandth of a millimetre. Their comparison demands accordingly methods of measurement of the very highest precision, such as are to be derived in the most exacting manner from the phenomenon of optical interference. At the Zeiss Works *Interference*

Comparators are made for comparing and recently also for determining the absolute measure of end-measuring and fixed-limit gauges in accordance with the suggestions of Dr. Koesters, of the German Imperial Institute of Weights and Measures, as shown in fig. 187. For the application of this apparatus the two end-measuring gauges which are to be compared are placed in adhesive contact by two of their parallel end faces, whilst a glass plate covering the other two faces is made to approach them sufficiently closely to give rise to interference figures between them and the plate. The position of the interference figures supplies a measure of the difference of length subsisting between the two pieces.

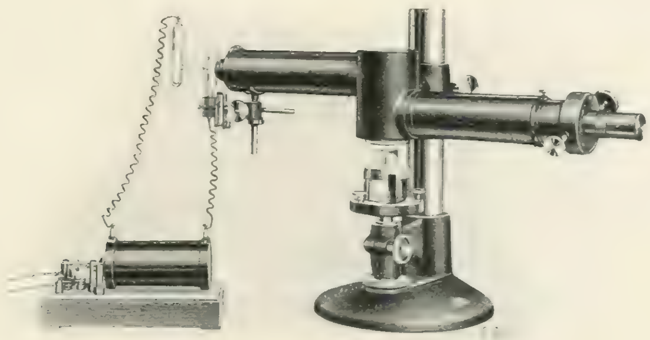


Fig. 187. Interference Comparator.

By the creation of the new implements described in the preceding pages the Zeiss Works addressed its energies to an entirely new world of consumers. In the ordinary course of things the introduction of the new appliances would have necessitated the institution of an entirely different marketing organisation. To obviate this necessity the firm entered in 1919 into a contract with the Schuchardt & Schuette Company, of Berlin, whereby this firm undertook the entire sale and export of these tools and instruments. Apart from the commercial advantage of this arrangement it provided the makers with a most excellent source of information affecting all questions of the requirements arising in mechanical engineering.

The Spectacle (Opto) Department and the Medico-optical (Med) Department.

When a large undertaking grows from small beginnings into a complex organisation it is often interesting, in more than one respect, to trace the course of its gradual development and to observe to what extent is has swerved from the logically predicted course, only to finally once more return to certain points whence it issued forth. The history of the Zeiss Works presents excellent material for such reflections.

The Jena Works had derived its first nutriment from the call of the natural sciences and medicine. The instrument to which it owes its first and foremost development was the microscope, which more than any other of the tools of medical progress stands prominently forward in the service of medical research and practical medicine as well as in the allied biological and auxiliary disciplines. Subsequently entirely different problems stood to the front in the activities of the establishment, and it was not long before purely technical production, notably of a topographical, military and naval character, became the dominant interest. Such was the effect of the Great War. But, in the course of the last few years a return has been made to the original problems, only with a vastly extended program to meet the requirements created by the march of medical science and practice.

Incidentally, it may at first sight appear astounding that such a vast undertaking as the Zeiss Works, whose aim would almost seem to have been to engulf, as it were, the whole domain of instrumental optics, yet for the space of half a century should have ignored that very optical device which in point of simplicity and human significance stands at the head of practical optics. We are referring to that simple and ubiquitously beneficent device known as spectacles. Actually, however, the explanation is not so very far to seek. Spectacle lenses are very simple things to make so long as it is deemed sufficient to supply the rough and ready thing which contents the uncritical and unknowing multitude. Undoubtedly, we can see better with the ordinary type of spectacles than without them, in many cases very much better, but this does not by a long way dispose of the question as to whether we see with them so well as it is possible to do. Such an establishment as the Jena Works was not likely to enter upon the manufacture of spectacle lenses until scientific investigations by notable ophthalmologists of the underlying problems had furnished an answer to that question in its fundamental bearings and prepared its practical solution. When this stage had been reached it still needed the

wide experience in theoretical and practical optics which Prof. M. von Rohr of the scientific staff of the Zeiss Works was able to bring to bear upon the subject before the first trigonometrical computation of a new order of scientific spectacle lenses could be carried out.

Spectacles and medico-optical instruments are made at the Zeiss Works under the control of Prof. O. Henker. Spectacle lenses, considered as a scientific proposition, involve an attack upon an entirely new problem inasmuch as it demands the creation of a stationary optical instrument which shall be capable of forming a good optical image in conjunction with another, but this time, movable optical instrument — the eye —, no matter what their relative position may be. In the construction of purely inorganic optical instruments, such as the microscope and telescope, the problem is restricted to the combination of successive stationary instruments. The eye, which in many respects is a very imperfect optical instrument, derives its magnificent seeing powers in a prominent measure from its mobility. The chief process by which we are enabled to locate objects in space is that implied in the popular term "looking". During this process the eyeball turns rapidly as in a ball-and-socket joint about a point situated near the centre of its cavity. We really see the whole of an extensive object by looking at its interesting details in rapid succession or fixing the sight upon a certain point, so as to project an image of it upon the best spot on the retina. An optical device which was specially adapted for the looking eye was computed as long ago as 1902 at the initiative of Prof. Gullstrand. This was the "Verant" lens. Behind this form of magnifying lens the eye is able to move about its point of rotation as in unaided vision and is able to see distinctly in all directions. This is an advantage of paramount importance which would go far to restore the natural seeing powers of spectacle wearers. When an eye looks through an ordinary spectacle lens it may, no doubt, obtain good vision so long as it looks through the middle of the lens, but as it proceeds to turn behind the lens so as to look through portions of the lens which more and more approach the rim of the lens it sees less and less distinctly in consequence of the resulting astigmatism of oblique pencils to which the outer portions of the lens give rise, and hence, owing to the defective quality of the image, the eye does not receive any distinct impression when it looks through a portion near the rim of the spectacle lens. In these circumstances the natural mobility of the eye cannot be taken full advantage of. The eye of a spectacle wearer involuntarily always seeks out those portions of the lens which enable him to see satisfactorily. Obviously, this occasions a restriction in the movements of the eye which has to be supplemented

by movements of the entire head. By an appropriate choice of the bounding spherical surfaces of the lens it is possible to find a sight-correcting spectacle lens of such a form that the eye, while looking about and through the spectacle lens in any direction up to the rim of the lens may obtain distinct vision. Spectacle lenses which fulfil this requirement may, after the manner of Prof. Gullstrand, be defined as *point-defining* or *point-focal* lenses. Those made at the Zeiss Works are named *Punktal Lenses*. The Verant lens may thus be regarded in a sense as the parent lens of the Punktal lens. The computation and manufacture of point-focal spectacle lenses was begun in 1908.

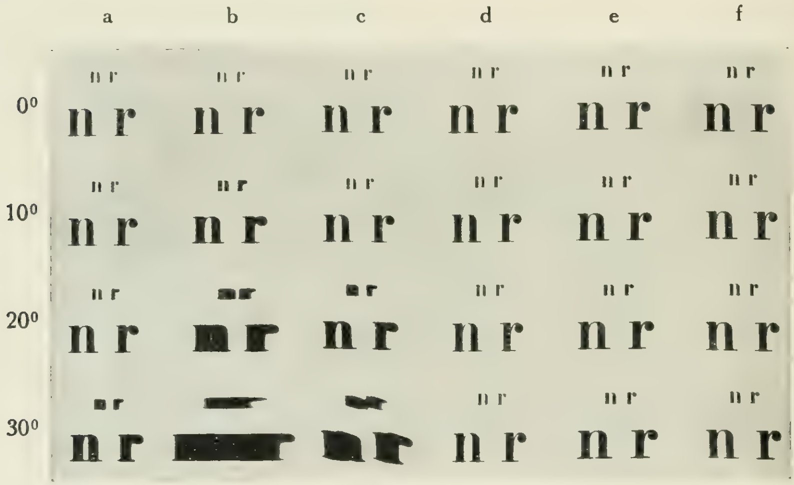


Fig. 188.

a b c Photographic reproduction of the letters *n r* through a sphero-cylindrical lens $+4$ $+7$ D.
d e f „ „ „ „ „ „ „ „ an astigmatic Punktal Lens of $+4$ $+7$ D.
a and d: with the lens rotated in the plane containing the axis of the cylinder;
b „ e „ „ „ „ at right angles to the axis of the cylinder;
c „ f „ „ „ in a plane at an angle of 45° to the axis of the cylinder.

A further difficulty which stands in the way of the spectacle problem is the fact that the eyes of many persons needing spectacles are astigmatic in themselves, that is to say, they cause points to appear, not as points, but rather as lines or star-like figures (for instance like stars in the sky, whence the term). Such an eye can only be corrected by means of a spectacle lens which to an eye looking through its centre exhibits a like amount of astigmatism as the eye but of the opposite sense, so as to neutralise the amount of astigmatism with which the eye happens to be afflicted. Hitherto it was usual in most cases to correct these anomalies with the aid of cylindrical lenses or sphero-cylindrical lenses. Now, in

order that an astigmatic eye may see distinctly through a spectacle lens, no matter in what direction the eye may be looking, it is essential that the amount of astigmatism applied at the centre of the spectacle lens should be maintained throughout the whole extent of the lens surface in the matter both of magnitude and direction for every possible angle in which the eye may look through the lens. It is only under these conditions that a distinct image point may be formed on the retina of an object point situated away from the axis, in other words, that a point-focal definition may result. The usual sphero-cylindrical lenses do not fulfil this requirement by any means, as may be clearly seen from the appearances reproduced in fig. 188, which also serves to show that the astigmatic Punktal lenses behave very differently. The astigmatic Punktal lenses belong to the category of sphero-toric lenses. A toric surface may be described as a portion of a barrel or ring surface. When light passes through it one of its effects is comparable to that of a cylinder. A sphero-toric lens is accordingly a spectacle lens which is bounded on one side by such a toric surface and on the other by a spherical surface. At the centre this lens behaves like a sphero-cylindrical lens. By a peculiarly fortunate coincidence it so happens that the most commonly occurring anomalies of sight can be corrected by the available spherical and spherotoric Punktal lenses.

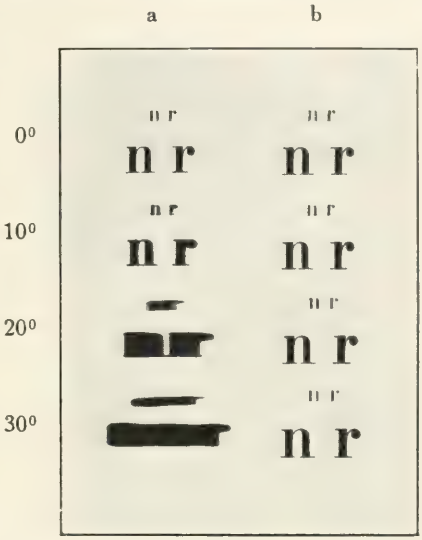


Fig. 189.

a) Photographic reproductions of the letters *n r* through a biconvex cataract lens of 13 D.

b) Photographic reproductions of the letters *n r* through a Katral lens of 13 D.

There is, however, one category of eye-cripples whose affliction cannot be relieved by a point-focal lens bounded by two surfaces of this kind. These are persons who have been operated for cataract. As our readers

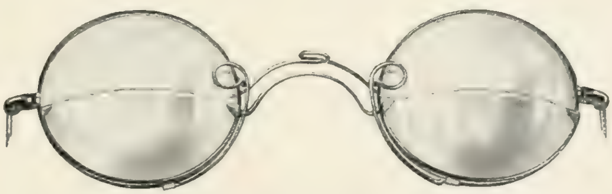


Fig. 190. Distance Spectacles with extra fronts attached.

will know, there are a number of persons who in advanced age partially lose their sight by partial or complete clouding of the lens of the eye. This affliction is known as the "grey cataract". The resulting loss of sight can be restored by the surgical removal of the lens. The aphakic, or lens-less, eye of a person operated for cataract requires in the great majority of cases such a strong positive lens that point-focal relations cannot be

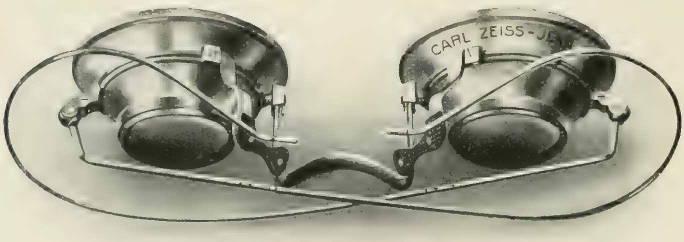


Fig. 191. Telescopic Spectacles for use in extreme myopia.

realised without having recourse to a non-spherical or so-called "figured" surface. The introduction of this figured surface was suggested by Prof. Gullstrand. The difference in the visual effect of an ordinary biconvex cataract lens and a Katral lens (i. e. a Gullstrand cataract lens with a figured surface) is to be gathered from fig. 189. That the enlarged field of view is a matter of paramount importance to a person operated for cataract while walking, ascending stairs and so forth is too obvious to need stressing.

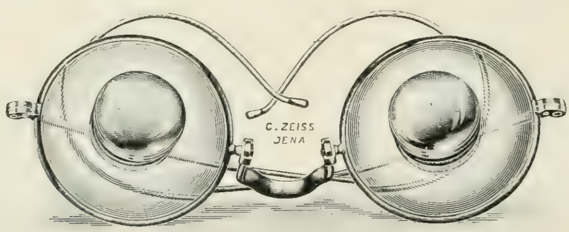


Fig. 192. Spectacle Magnifiers for spectacle wearers.

More or less aged persons who through presbyopia have lost, wholly or partially, the power of accommodation for varying distances, generally require two different spectacles, one for distance, the other for reading or working upon near objects. The Zeiss extra spectacle fronts or front lens attachments are supplements to distance spectacles, whereby the latter

become likewise available for use as reading spectacles. The combination of distance glasses and the front lens attachment, as shown in fig. 190, has, amongst others, the following advantages. — In making a transition from the "distance" to the "near" segment there are no disturbing breaks; the eyes see clearly and distinctly through both segments up to the edge; and the front lenses can at any moment be detached by a simple movement of the hand when full advantage is to be taken of the entire large field of view of the "distance" glasses.

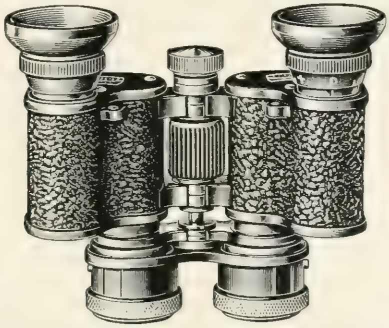


Fig. 193. Binocular Telescopic Magnifiers.

Persons afflicted with extreme myopia very frequently also suffer from diminished visual acuity and often cannot wear their ordinary fully correcting spectacles, which occasions a still further decline of their capacity of vision. The telescopic spectacles devised at the initiative of Prof. Hertel serve in this way to aid the impaired vision of eyes which are both near-sighted and weak-sighted. As will be seen from fig. 191, they are constructed after the manner of small Dutch

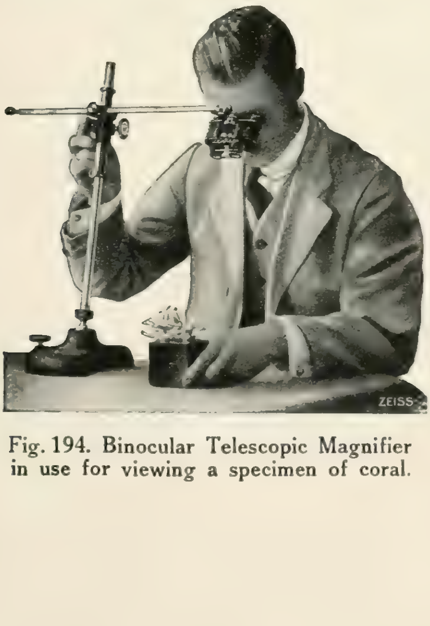


Fig. 194. Binocular Telescopic Magnifier in use for viewing a specimen of coral.

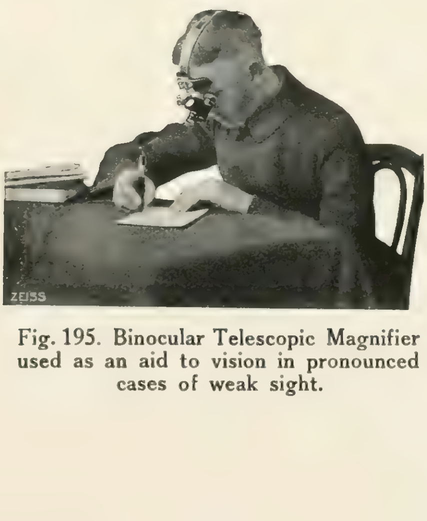


Fig. 195. Binocular Telescopic Magnifier used as an aid to vision in pronounced cases of weak sight.

telescopes. The resulting magnifications are naturally but small. They are made in the form of spectacles and lorgnettes and magnify only up to two times. These telescopic spectacles are also made on a similar plan for normal-sighted persons and for spectacle wearers with only slightly anomalous vision. Where telescopic spectacles are required for near work only they may be made in a specially light form as *spectacle magnifiers,* as shown in fig. 192. These are particularly useful for doing fine work which does not permit of the object being approached sufficiently closely. In the case of persons whose visual acuity is very seriously impaired, improvement, if not by means of spectacles, may yet be effected with the aid of comparatively small instruments, the so-called *telescopic magnifiers,* as shown in figs. 193, 194 and 195. These are monocular or binocular instruments which are capable of producing a magnified image of distant or also near objects. When they are employed for viewing near objects the objective of the prism telescope has appended to it a magnifier lens, the so-called front lens attachment. Thanks to the many uses to which these instruments can be applied they offer valuable assistance in many scientific and technical operations. This is owing to the fact that, when used as magnifiers, they can be held a comparatively long distance away from the object and also to the ease with which their magnifying power can be varied by simply changing the front lens.

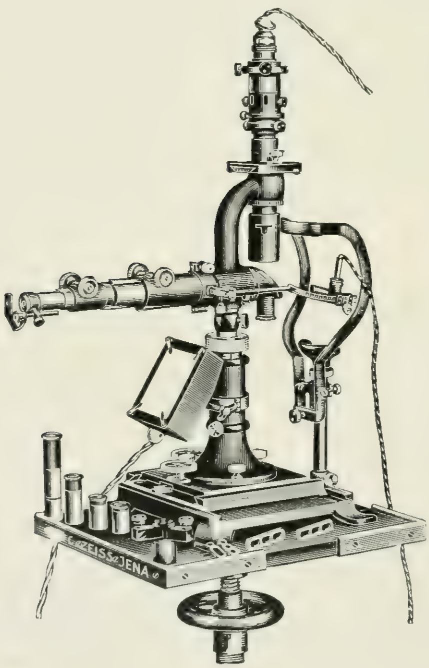


Fig. 196. Large Gullstrand Ophthalmoscope.

The telescopic magnifiers come already in a transitional sense within the scope of the Medical Instrument Department. They belong more especially to the category of optical instruments for ophthalmic examinations in the consulting room. A few ophthalmological instruments had already been manufactured in the Measuring Instrument Department for several years before a Medical Instrument Department had been instituted. A number of modern clinical instruments have been constructed for the use of eye surgeons on the principles originated by the well-known ophthalmologist Prof. Gullstrand, of the University of Upsala. First among these should be mentioned the large

Gullstrand *ophthalmoscope,* by means of which the fundus of the eye can be viewed without interference from injurious reflections (fig. 196). When provided with a monocular viewing arrangement, the retina of the patient can be examined at various widely differing magnifications by way of its erect image. The illumination in this case is furnished by a special optical system with a Nitra lamp as a source of light. A particularly fine view is obtained when the instrument is arranged for observation with both eyes, as in this case the vessels of the retina are seen with beautiful distinctness in relief, that is, in their natural positions in space. The large ophthalmoscope can be furnished with an eyepiece by means of which two observers may jointly view the same portion of the fundus of the eye in like position and illuminated in like manner. This instrument can also be equipped with a drawing apparatus, with the aid of which an observer is enabled to trace on paper the image of the retina.

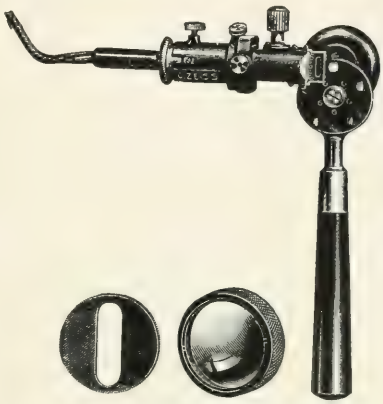


Fig. 197. Monocular Gullstrand Hand Ophthalmoscope.

Two kinds of eye fixation devices are provided, by means of which the surgeon can ascertain and fix the direction in which the patient's eye is looking. He is thus enabled to study in detail any particular spot on the retina. The advantages of this method of observation without having to contend with internal reflections as applied by Gullstrand to the fundus of the eye have been embodied by him in the construction of two hand instruments, viz. a monocular and a binocular *hand ophthalmoscope,* the former of which is shown in fig. 197. In both instruments the illumination is furnished by a small electric filament lamp. Another instrument which is capable of rendering frequent and valuable service to the surgeon is the Gullstrand slit lamp, with which the different portions of the eye can be illuminated with intense focal light. This illuminating apparatus has provided Prof. Vogt, of Basle, and Prof. Koeppe, of Halle, with the means of developing a system of microscopy of the living eye. The instruments of observation employed for this purpose are the binocular corneal microscope first propounded by the late Prof. Czapski (fig. 198) and the binocular eye microscope introduced at the instance of Prof. Koeppe (fig. 199). When details of the iridic chamber and the posterior segment of the vitreous, including the retina, are to be viewed, which may be done under magnifications up to 100 diameters, it becomes necessary to employ special eye

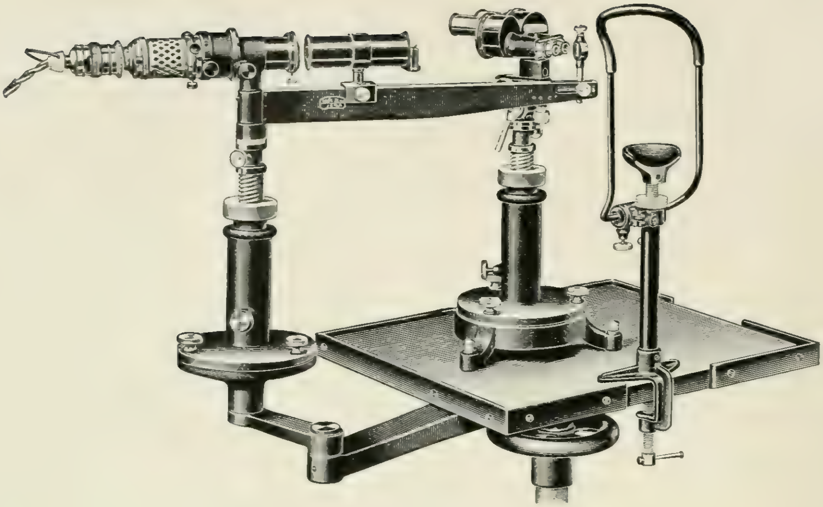


Fig. 198.
Corneal Microscope with a Gullstrand Slit-lamp on a radial double bar.

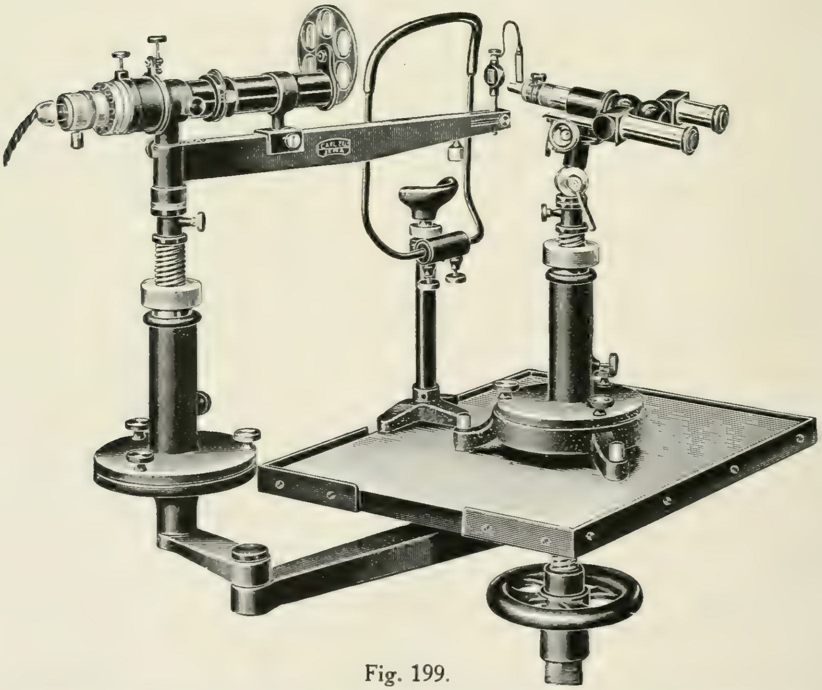


Fig. 199.
Koeppe Eye Microscope with a Gullstrand Slit-lamp on a radial double bar.

adhesion lenses, which are placed upon the patient's eye after the latter has been rendered insensitive by the application of a local anaesthetic. When fine blood vessels, especially structural details of the cornea and such like, are to be studied the investigation may be carried out with the aid of red-free as well as polarised light.

The *large simplified Gullstrand ophthalmoscope* is an all-round instrument for practical eye surgeons (fig. 200). This instrument serves for the monocular observation of the fundus of the eye by way of its erect image

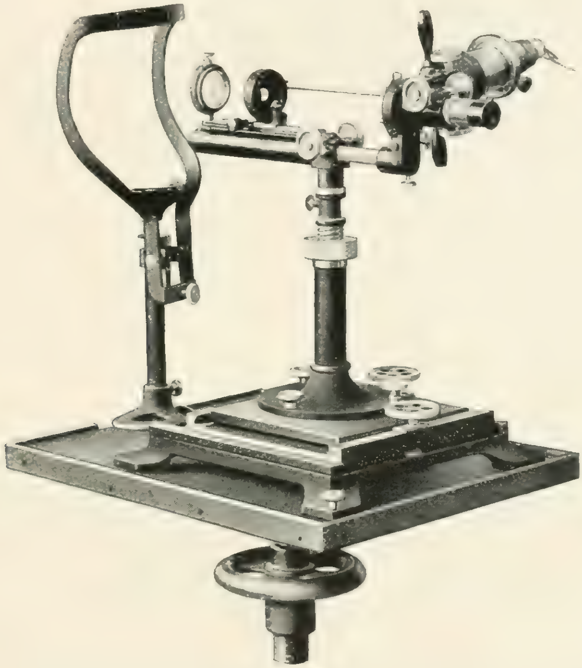


Fig. 200. Large Simplified Gullstrand Ophthalmoscope with the Henker parallax refractionometer.

magnified up to 40 times and also for its binocular observation by way of its inverted image magnified up to 20 times. This instrument can be transformed into a slit-lamp by a few simple manipulations. Hence, in conjunction with a corneal microscope or eye microscope, it is available for the examination of the eye by focal illumination. Moreover, in conjunction with a simple supplementary instrument devised by Prof. Henker this instrument becomes a refractionometer for determining the degree of departure from normal sight without the cooperation of the patient as well as the magnitude and axial direction of the total astigmatism of the eye.

An ophthalmological instrument which is primarily intended for instructional purposes takes the form of the *Wessely Demonstration Ophthalmoscope,* in which the demonstrator sees the same retinal image as the student. At the same time it affords the latter a clear insight into the methods of examination.

Another valuable ophthalmological instrument of recent construction which should be mentioned is the *Maddox phorometer* devised by Prof. Stock (fig. 201). This apparatus serves for determining, independently of the

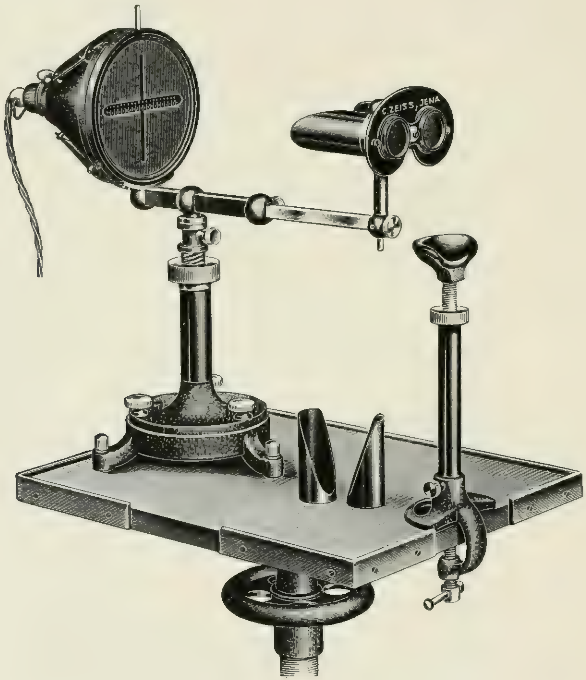


Fig. 201. Stock-Maddox Phorometer.

patient, squinting deviations in a transverse and vertical sense, both when looking at a distant and near object. Incidentally this device serves also for ascertaining whether the lenses of spectacles are mounted centrally in front of the eyes.

The *Differential Pupilloscope* (fig. 202), as originated by the Munich ophthalmologist Prof. C. von Hess, serves for investigating disturbances in the play of the pupils.

For the examination of the larynx Prof. Brünings, of Jena, has suggested a magnifying anastigmatic *laryngeal mirror,* with the aid of which

the larynx can be viewed magnified to about double its natural size. At the same time, the use of the mirror is as simple as that of an ordinary laryngeal mirror. This same principle has likewise been applied to the examination of the tympanic membrane. With the aid of Prof. Brünings' *ear speculum* the tympanic membrane may be examined by its perfectly sharply defined and magnified image *without interference from internal reflections.*

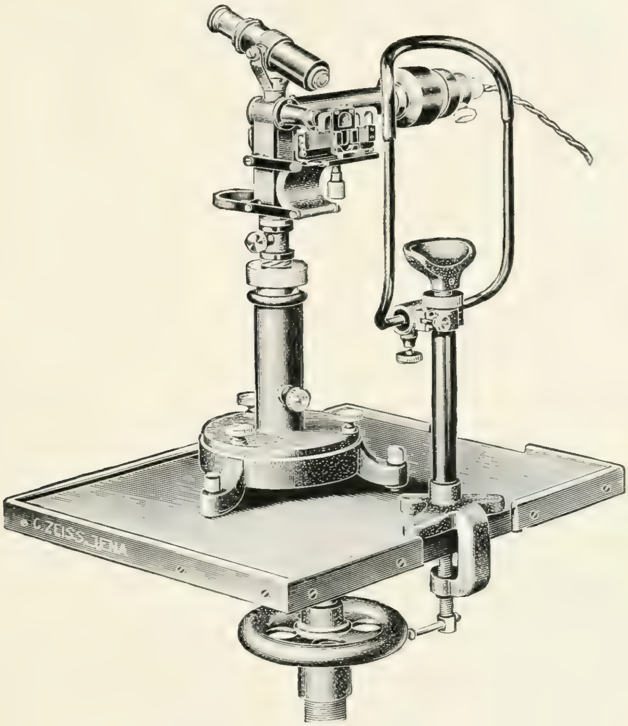


Fig. 202. C. von Hess's Differential Pupilloscope.

A *Polylaryngoscope* has been devised by Prof. Brünings more particularly for teaching purposes. By its means from two to eight students may view the larynx or tympanic membrane jointly with the demonstrator.

Cystoscopes of great light-transmitting capacity have been constructed on the initiative of Prof. O. Ringleb, of Charlottenburg. With the aid of these instruments the bladder, when filled with boric acid solution, may be examined without the use of the knife. The instruments, though small, are fitted, along with the optical viewing apparatus, with a small filament lamp for lighting up the area which is to be examined. It admits of a fairly

large field being surveyed under a sufficiently intense illumination. A *gastroscope* designed on a like principle serves for the internal illumination and examination of the stomach. For these endoscopic instruments the optical constituents only are made at the Jena works, whilst the complete instruments are supplied to the surgical profession by the G. Wolf Company, of Berlin.

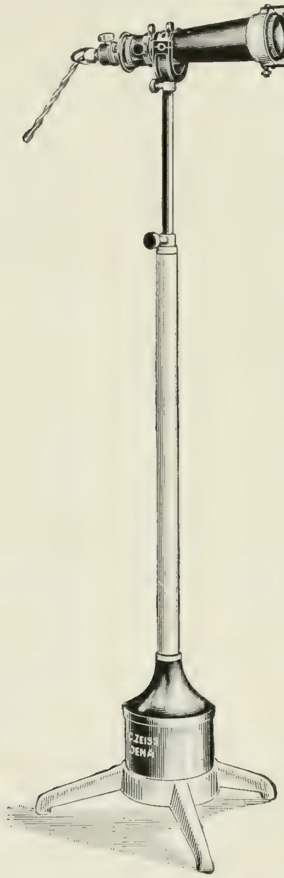


Fig. 203. Mouth Illuminating Apparatus with Nitra lamp.

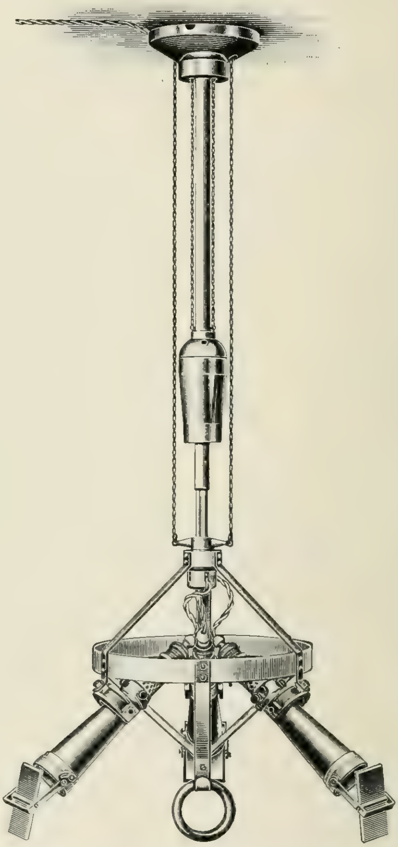


Fig. 204. Three-lamp Illuminating Apparatus for the operating table.

A number of *illuminating appliances* have likewise been devised for mainly medical purposes. Special interest among these attaches to the illuminating apparatus with continuous current arc-lamp and the illuminating apparatus with Nitra lamp. The various forms of this apparatus engender at a distance of a yard a sharply bounded circular patch of light of a great

and uniform intensity, which may be diminished in size by supplementary lenses, in which case the initially high intensity will rise still further. Thus, while the larger radiant field may be employed for lighting up the oral cavity in dental operations, a smaller radiant field may be made a means of bleaching discoloured teeth (fig. 203).

Similar devices, by means of which the light can be concentrated upon an object from various sides serve for illuminating the field of operation (fig. 204). The small *hammer lamp* suggested by Prof. von Hess (fig. 205) serves the same purpose and enables an assistant to attend to the illumination of a small field of operation.

Fig. 205. von Hess Hammer Lamp.

A form of illumination which is particularly well adapted for operating theatres owing to its shadow-dissolving qualities is derived from the so-called ball reflector lamps. These are either suspended from the ceilings or mounted upon stands running on casters (fig. 206).

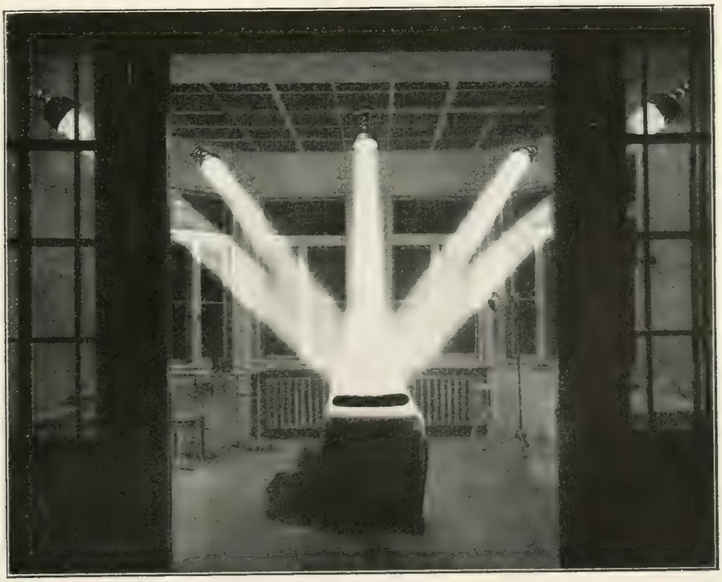


Fig. 206. Illumination of an operating theatre by means of ball reflector lamps.

The Vogt redfree lamp has been devised for the purposes of ophthalmoscopic observation with red-free light. It consists of a light-tight arrangement completely encasing an arc lamp of 5 or 10 ampères. The light of this lamp is received by a condenser, which can be made to supply a parallel, faintly converging, or diverging pencil of rays. In front of the condenser there is a blue-green colour filter, which eliminates from the light of the arc lamp every trace of red. When viewing the fundus of the eye with this redfree light all parts which are naturally coloured red appear black, whereas the differently coloured portions, such as the yellowish fovea, stand out prominently.

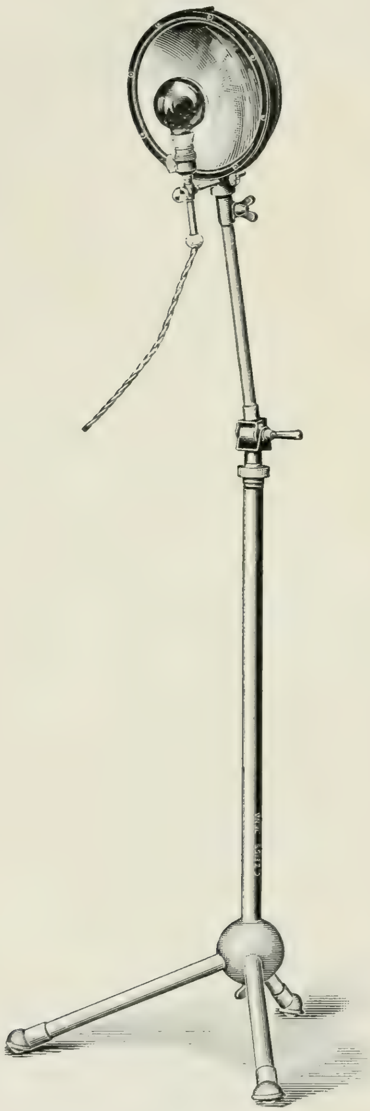


Fig. 207.
Simple Kisch Radiation Mirror.

Closely related to the illuminating appliances are those devised for therapeutic radiation.

The *radiation lamp,* which resembles the illuminating apparatus with Nitra lamp, contains for its source of light a 100-watt projection filament lamp. An artificial radiation by light equivalent to sunlight is furnished by the *Radiation Mirror* shown in fig. 207. This consists of a parabolic glass mirror of large diameter having near its principal focus a 100-watt projection filament lamp. At a distance of about half a yard from the mirror an oblong radiant patch forms measuring 8×7 cm., within which the radiated heat rises to about 70^0 C. Drs. Bier and Kisch, of Berlin, have obtained remarkable results by applying this mode of radiation to the treatment of tuberculosis of the bones, joints, glands, and skin. The *eye radiating apparatus* devised by Prof. Koeppe serves for the treatment of the morbid anterior and posterior segments of the eye with filtered arc light within a range of the spectrum extending from 350 to 500 $\mu\mu$.

The *redfree lamp* may be converted into a Birch-Hirschfeld radiation lamp by exchanging the illuminating tube for one furnished with a quartz condenser and uviol filter. This lamp serves for the ultraviolet treatment of inflammatory processes in the anterior segment of the eye. An additional quartz lens is necessary for focal radiation (fig. 208).

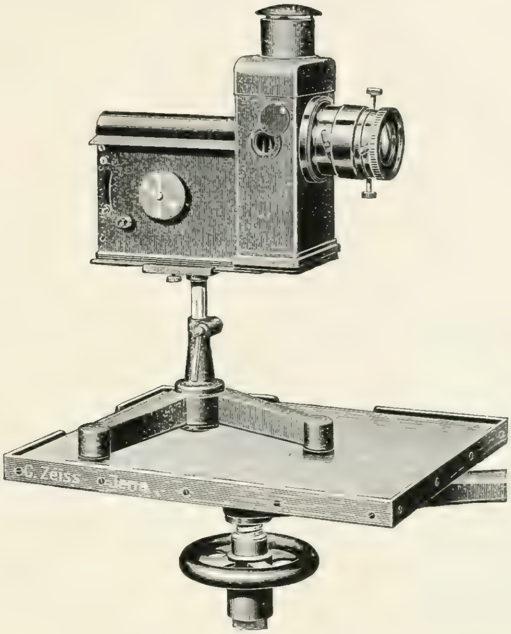


Fig. 208. Vogt Redfree Lamp.

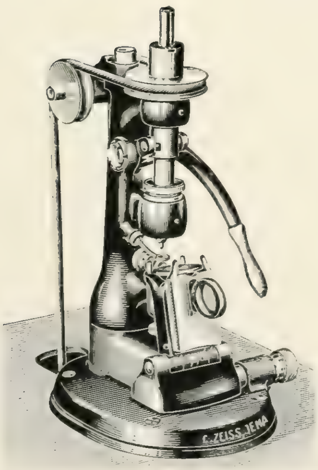


Fig. 209. Spectacle Lens Drilling Machine.

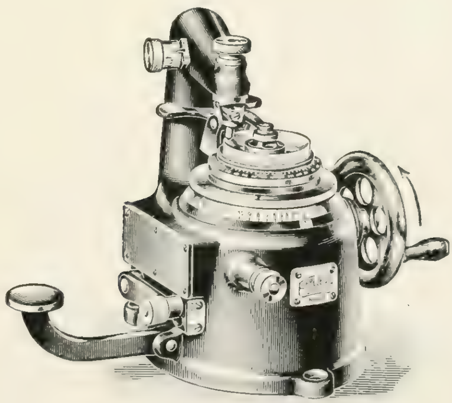


Fig. 210. Spectacle Lens Cutting Machine.

The instruments which are used by both oculists and opticians in order to ensure the correct position of the spectacles include the *interpupillary distance gauge.* This instrument takes into account the frequently occurring dissymmetry of the nose with respect to the two eyes, which has an important bearing upon the proper seating of the spectacles. The *Wessely keratometer* provides a means of measuring the width of the cornea. In addition, it is available for a very important measurement, viz. for determining the distance between the vertices of the cornea and the spectacle lens.

Fig. 211. Binocular Magnifier with illuminating attachment in use.

Devices which concern the optician only include *strain testers for spectacle lenses, Punktal lens demonstrating models, a spectacle lens drilling machine* and a *spectacle lens cutting machine* (figs. 209 and 210).

Mention should here be made of the *binocular magnifier* (fig. 211) for medical men, nature students, scientific instrument makers, etc., with the aid of which small solid objects can be viewed with both eyes. The advantage of this binocular magnifying arrangement is that both the details and the structural relations of the component parts of the solid object can be more distinctly and more easily recognised than can be done with the unaided eye.

In addition to these, monocular magnifiers are made for a great variety of purposes. The *Nommos magnifier* (fig. 212), a meniscal lens magnifying $2\frac{1}{2}$ times, serves for examining coins, medals, and such like. The *aplanatic*

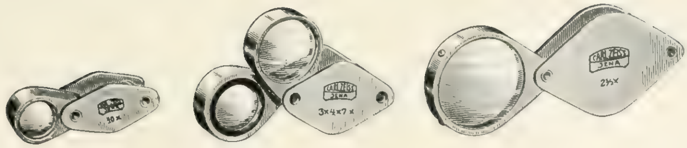


Fig. 212.
Aplanatic Folding Lenses, magnifying 3, 4, 7 and 10 times. Nommos magnifier.

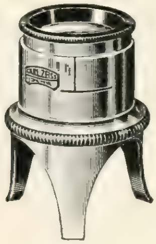


Fig. 213.
Aplanatic Magnifier on tripod.

Fig. 214.
Aplanatic Focussing Glass.

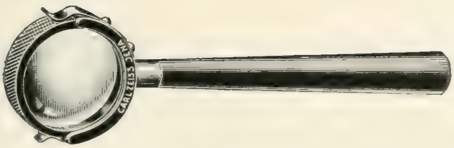


Fig. 215.
Aplanatic Figured Reading Lens.

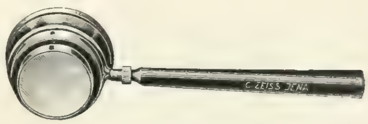


Fig. 216.
Albada Wide-angle Magnifier.

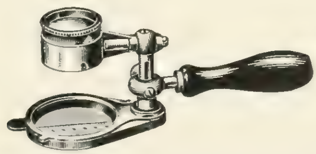


Fig. 217. Textile Gauging Magnifier.

Fig. 218. Monocle Lens.

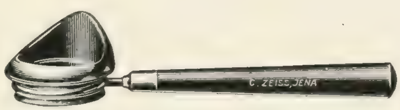


Fig. 219. Picture Viewing Lens.

magnifiers (figs. 212, 213 and 214), magnifying 6, 8 and 10 times, are improved Steinheil magnifiers composed of three mutually cemented lenses. The *"figured" (nonspherical) aplanatic reading lenses* (fig. 215), magnifying 3, 4, 5 or 8 times, are spherically corrected, free from distortion, and of large aperture.

The *Albada wide-angle lens* (fig. 216) magnifies about 2·8 times and serves for general surveys.

Where the size of the field of view is less a matter of importance, photographs and such like may be viewed with the astigmatically corrected *picture viewers* or the *Verant Lenses,* the latter having the additional advantage of being free from distortion and colour defects. The picture viewers, Verant lenses, and the *monocle magnifiers,* which are well adapted for fine technical work, are made in various sizes magnifying 1·7, 2·2, 2·8 and 3 times (figs. 217 to 219).

Lighting Department.

This, the youngest department of the Zeiss Works, is concerned with the manufacture and marketing of a new form of reflector lamp. Like the ball reflector lamp designed for the illumination of the operating table, as described on page 169, this new lamp is furnished with a silvered parabolic

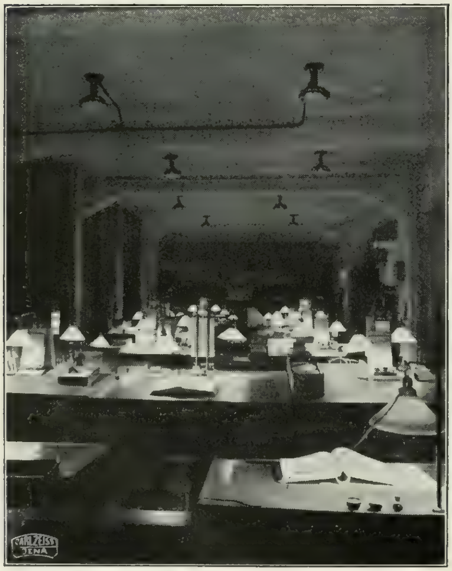


Fig. 220. Old method of lighting offices by means of desk lamps.

The new system of illumination by means of Zeiss reflector lamps.

glass mirror. The yield of the source of light, which is in the form of an ordinary bulb lamp with annular filament, is very largely increased, so that a given area may be brightly lit up at a small expenditure of current. The lamp may be used singly for lighting up work places, writing tables, pianos, etc. or several lamps may be grouped together for lighting offices, as shown in the two comparison views of fig. 220, also for lighting workshops, exhibition halls, and show windows.

We have now reviewed in descriptive catalogue fashion the scope of the various departments of the Zeiss Works, and yet there is still one other aspect which has escaped our attention. It will be realised, that, in a large undertaking which is continually faced with new problems arising out of the progressive life which it serves, every now and again new devices come into existence which cannot be made to fit the scope of any of the existing departments, but rather extend to two or more, if they do not inevitably lead to the institution of a new department. The working out of these special problems, some of which have already been referred to incidentally, devolves to a great extent upon the scientific heads of the establishment and likewise engages the efforts of several of the younger members of the scientific staff.

In this category are to be reckoned numerous instruments and appliances for specialised branches of science, such as physiology, chemistry and technology, made up of the component elements of the microscope, the stereoscope, the polariscope, and other instruments.

Development and Organisation.

The insight into the objects and efforts of the Jena establishment which we have derived from the preceding survey is defective in one notable particular, notwithstandig the varied information which we have gleaned and the many impressions which we may have received, or possibly on that very account. The defect of our survey is that it suffered from local detachment, which rendered it too abstract. In order to infuse into it concrete life we can do no better than enter, so to speak, the workshops themselves and watch the processes by which the raw materials are transformed into those many and varied devices which we have briefly reviewed in the preceding portion of this book. Before we carry out this imaginary ramble we shall materially add to the interest of the processes to be described by interposing a short historical sketch of the practical beginnings, the development and the growth of the establishment, and by noting the changes in its organisations which arose with the change of conditions.

For our starting point we may take what has already been related on page 3 and the succeeding pages.

The workshop founded by Carl Zeiss in 1846 had its first modest home in the Neugasse and soon after it was moved to the Wagnergasse (Pictures of both premises have already been shown on page 5). These shops were rented rooms meagerly fitted up to answer their purpose. Here Zeiss began operations with one journeyman and two apprentices, and for some time after his staff of workmen was not increased to any noticeable extent.

There is only one surviver of those old days, old Herr Loeber. To anyone who is intimately acquainted with the giant establishment of to-day it is like an echo of bygone romance to listen to an account of those humble beginnings as told with the delightful simplicity and quaintness of the old eye witness. In the words of old Loeber:

"Since there was not always enough to do in glass work I had sometimes to take a hand in brass work as well. In 1848 (the year of the German revolution) Herr Zeiss was in the citizens' corps, and, as there was little doing in the way of business, old flint locks were converted into percussion locks, locks had to be filed and occasionally also to be hardened . . . . Apart from this year of revolution, the business met with set-backs later in the fifties owing to commercial crises and high prices, so much so that the journeyman had to be discharged, with the result that Herr Zeiss and your humble servant constituted the entire staff . . . . . . From all this it will be seen that the fleshpots of Egypt were none too well filled at times. I remember occasions when Herr Zeiss breakfasted on three-pfennig (1/3 d) worth of black rolls and a small gin. I have not only seen this, but I have even had the good luck to receive a mouthful of gin if I happened to come upon my principal during such a repast . . . . . And so it happened not infrequently that I was fetched away from my Sunday occupation (gardening) for the sake of a measly pair of spectacles costing 1/9. You will understand why I never developed obesity."

In 1857 the workshop was transferred to a rather more commodious site on the Johannisplatz (fig. 221) which provided facilities for extension and "promised" to suffice for long years to come, if not for ever. It was an agreeable disillusionment when the promise was completely broken. True, during the life of the Johannisplatz factory the establishment was able to celebrate three fine events, viz.

on the 28th May 1866 the completion of the 1000th microscope,
on the 12th January 1873 that of the 2000th microscope,
towards the end of 1876 that of the 3000th microscope,

but with the latter crowning event the establishment had also nearly reached

its limit of expansion. Thanks to the invention of the homogeneous immersion lens and the increasing favour which the Zeiss products in general were then already enjoying the number of workmen employed had gradually risen to about fifty, and after that their number grew more rapidly.

In consequence of this growth an extensive site was acquired in 1880 in a part of Jena which in those days was situated almost outside the town. The chosen locality was situated between the Krautgasse and the Leutrabach, on one side of the present Carl-Zeiss-Platz. Immediately after the acquisition of this site the erection of well lighted and airy buildings was proceeded with. If it had been possible then to foresee at what rate the town of Jena and the Zeiss Works were destined to grow, one reacting upon the other, it is certain that already in 1880 a site would have been chosen in a more outlying part of the town area. The advantage which the establishment derives at present from the fact that the several blocks which it comprises (see the view at the end of the book) are situated at the centre of the town is largely vitiated by the disadvantage that ground which in the mean time had been covered with private buildings had to be acquired at enormously high prices and that the time is in sight when it will no more be possible to make any extensions on the existing site. Within the period during which the author has been privileged to watch with his own eyes the development of the undertaking, that is to say since 1890, scarcely a year has passed in which a new building of stately proportions has not been added or in which some existing building has not been extended, as will be seen from the historical plan at the end of the book. Thus, in 1913 it became necessary to break up the old simple home in which Abbe had spent the greater part of his life with his family. At present the establishment occupies an area of about 125 acres, more than one half of which is covered with buildings. All the later buildings are constructed of reinforced concrete. The loftiness of the workshops, the heating and ventilation, which have been carefully designed on the most modern principles, the light-admitting openings with an aggregate area of 80 per cent of the enclosing surface, all these factors contribute to invest service in the establishment with the utmost degree of comfort.

Fig. 221. The third workshop (in the Johannisplatz).

We will now cast an eye upon the *organisation* of the business, that factor which perhaps more than any other determines the prosperity or failure of an undertaking.

From what we have already learned of the history of the Zeiss Works we are not likely to conclude that the organisation of the huge establishment has arisen overnight. On the contrary, continually growing and at times spasmodically changing conditions called for a new system in the works management and general administration. There was one thing only which throughout all changes stood firm as a rock. For it remained the inalterable aim of this organisation to extract the utmost degree of efficiency from the human and mechanical effort which it was able to put forward. This, however, is attainable only where means are found to reduce to a minimum all internal frictions, all fruitless resistance and idly running machinery, all factors, indeed, which tend to inhibit the output. To reduce these evils to a minimum is the utmost that is achievable, since it is in the nature of all human institutions that they refuse to eliminate all obstacles. It is also clear that in a measure as the whole progresses and increases in magnitude the attainment of that ideal aim becomes more and more difficult but also more and more imperative. In all that goes towards the ultimate achievement of success a logical and intelligent organisation dominating the whole naturally occupies the foremost position, but over and above this there is the human element which plays a scarcely less important part, for it is essential to the success of the whole that each participant should take an interest in its wellbeing and that each should realise the necessity of conscientious cooperation. And as in all phases of human effort, the helping hand of good fortune was not without its influence upon the success of the Zeiss Works, though more often than not good fortune has a deeper foundation than is to be found in the caprices of destiny. The Zeiss Works have indeed been favoured by good fortune in the discovery at all times of the right personalities to cope with the great problems which arose from time to time, but let it be clearly understood that we must not apply the word personality in its narrower sense to the controlling intelligences only, but also, in its appropriately extended meaning, to any and every operative who performs his work in a consciously purposeful spirit.

In the first two decades of the firm's existence Carl Zeiss, the proprietor of the small establishment, united all functions in his own person. He was the leading craftsman in his workshop, his own bookkeeper, correspondent and cashier. After the admission into partnership of Abbe the organisation underwent a series of modifications. The scientific, technical and commercial

work at least were separated to some extent, but organisation in a complete sense was not ever reached in the days of Abbe. Neither need this surprise us, for we must never forget that the great and many-sided man was and remained by the very alpha and omega of his nature the lofty savant and an idealist, and, moreover, his own pre-eminence could not in the nature of things favour the development of a mechanicalised organisation. It may grieve the heart that in the end such a mechanical organisation has come into being, but an intelligent critic willing to accept the inevitable will not be too ready to deny that it was in the interest of the whole that matters should thus develop.

The organisation applied within the Zeiss Works has introduced a far-reaching system of *centralisation* in all matters relating to manufacture, commercial management, administration and the technical operations of the plant. At the same time, a certain degree of *decentralisation* remained, so as to leave room for that amount of specialisation which alone is conceivable in view of the enormous diversity of the objects of manufacture and the scientific and technical problems which enter into the life purpose of the great establishment. The establishment as a whole bears accordingly the character of a unit inasmuch as it comprises *one* factory, *one* aggregate of linked workshops, *one* central controlling business system and works management. But these are associated with certain more or less independent technical, scientific, and even commercial branch sections, to some extent even with self-contained workshop sections of the instrument groups which we have reviewed in the first section of this book, such as microscopes, telescopes, spectacle lenses, etc. The system of detachment was by no means the result of an inflexible programme, for, as a matter of fact, occasionally fusions of one section with another occurred if their character rendered this desirable, and in some cases fusions followed upon ordinary historical developments. Then again specialisation followed as an imperative necessity in the train of extensive scientific investigations, which play such a prominent part in the realm of optics and frequently cut deeply into the wide-spreading branches of the natural sciences and their technical and industrial applications. In some cases the main business control fell into the hands of individual departments rather than those of the central management.

The bridge between the scientific departments and the workshops is established by the joint *drawing offices,* of which there are four at present, providing accommodation for some two-hundred engineers, designers, and draftsmen. Here all new propositions and improvements are worked out and drawn in detail. The first beginnings of these drawing-offices date

back to the middle of the eighties, when Mr. Max Berger entered the service of the firm as its first designer and draftsman. Until then new forms and changes of existing forms had been evolved at the bench rather than on the drawing-board.

In addition, there are a separate laboratory for testing optical glass, a chemical laboratory, an establishment for testing the whole of the raw materials which enter into the manufacture. All these are important provisions for enhancing and permanently ensuring the established quality of the finished instruments and other products in general.

The entire *commercial management* engages at present a staff of more than two-hundred persons. The whole is cut up into many subdivisions for dealing with general matters relating to the works management, cost calculation, buying and selling, control of stock, finance and counting house business, enquiries, correspondence, head office and branch office accounts.

The magnitude of the work which devolves upon all these departments may be gathered from the fact that there are about two-thousand suppliers of materials and finished goods and over twelve thousand buying customers to be dealt with. Moreover, it must be borne in mind that the material used in manufacture and other goods used in conjunction with these have to be derived from a widely ranging variety of sources and that many materials are of a kind which is not easily obtainable in the required quality. Probably few of our readers can realise the amount of trouble which it costs to obtain crystals, for example, of a suitable nature for optical purposes, such as calcspar, fluorite, quartz, etc. The enormous correspondence of the establishment is conducted in German, English, French and Spanish. The word "enormous" will not seem an exaggeration when the reader is told that the average daily number of incoming and outgoing letters is about two-thousand, and that about a hundred telegrams are received and sent out in the course of a day. The counting house, apart from a very large mass of money transactions and banking business, is kept heavily engaged in the matter of payments of salaries and wages to some five thousand employees of all grades. The fact that in the great majority of cases the waging is founded on the piece-work principle, instead of being based on time rate, adds considerably to the complexity of the task, and it will be realised that the amounts involved run into many thousands of pounds sterling per week and considerably over a million in the course of a year.

Our reference to piece work rate of waging brings us to another subject, that of *prime cost calculation,* in which the wage question always plays a very significant part, while in the Zeiss establishment it is nothing

less than the governing factor. In view of the nature of the products a comparatively small proportion of the total cost falls upon the material, while the work expended upon it absorbs by far the greater part. The gradual changes through which the significance of the question of prime cost calculation has passed reflects with interesting clearness the historical development of the undertaking. When Abbe entered the firm as a partner it was not difficult within the small compass of the firm's manufacturing and business operations to calculate the initial cost of its output. Also, so long as the quality of the new microscopes was able to defy competition profits were sufficiently high to render it unnecessary to apply an over-meticulous precision to the calculation of the cost of production. All this underwent a radical change when articles of all kinds made in large numbers, if not on the actual lines of mass production, came within the range of the firm's manufacturing operations and when these had to contend with a keen competition with the improved products of other makers at home and abroad. The inevitable consequence of these changes was that to-day the prime cost calculation, as carried out at the Jena works, has grown into an elaborate system, the results of which in their turn naturally react upon the methods of manufacture and upon the selling prices. It is not in a small measure owing to this economic and competitive element and its skillful handling that new methods of working, simpler or improved designs, and the use of some new material became the compelling agents of technical progress.

The *control* of the entire inventory, the stores of prepared and finished materials, etc., is in the hands of the *works management*. Another department deals with the selling market. Since more than one half of the products are sent abroad it goes without saying that a very complete knowledge of all matters relating to carriage and duties all over the globe are of the utmost importance in such a widely extending business organisation. Inimical customs barriers and the equally prohibitive methods by which the customs regulations are applied to German import in many countries place enormous difficulties in the way of business, and frequently protracted negociations are needed to obtain an intelligible interpretation of certain customs laws.

All matters relating to *publicity* are conducted by the literature office. The advertising media employed require in every case to be adapted to suit the nature of the goods and the aspects of the prospective purchasers as well as the range of the buying public. It may be taken as a fairly generally accepted business axiom that the worth of advertising increases with the volume of the prospective buyers. In the case of the Zeiss

establishment the publicity endeavours address themselves partly to the retail trade and partly to the ultimate user. The latter comprises scientific and technical institutions, hospitals and medical schools, laboratories, the medical profession, and so forth; next, almost every conceivable branch of industry, and finally the great public. These potential purchasers are all interested, according to their preoccupations, in different objects. A general catalogue, such as is issued by many other manufacturers, does not exist, therefore, in the case of the Zeiss Works. These catalogues, pamphlets and leaflets are issued in several languages, in some cases in as many as fourteen. The editions vary greatly with the subject of the publication. As many as 500,000 copies have been known to go to an impression, while the number of electros for the illustration of these publications has swelled to about 15,000. These, in conjunction with a likewise very extensive collection of photographs and lantern slides provide a magnificent wealth of material for the demonstration of a wide range of problems, phenomena and their scientific and technical applications throughout the entire vast realm of optics. Incidentally this collection is always available to applicants, by way of loans, for the illustration of lectures, scientific papers, newspaper articles, books, etc.

Fig. 222.
The Zeiss Trademark.

Naturally, one of the principal vehicles of publication takes the form of advertisements pure and simple. Advertising is done mainly through the medium of scientific and technical periodicals and illustrated journals having a very wide circulation. At the present time Zeiss advertisements are to be seen in all parts of the world ranging from the Far East to the extreme West as far as San Francisco. They have familiarised the famous trademark of the firm, which bears the contours of a composite lens, forcibly, yet in neat simplicity suggesting that the advertisement relates to optics. The retailers of Zeiss products are assisted in their efforts to inform the public by a fine array of show-cards and pictures, which are continually kept up-to-date. Moreover, the literature department is always there to support the retailers with information and material for their business efforts. For this purpose a home journal bearing the title "Zeiss Notes" is published and distributed among the dealers.

Considerable significance attaches also to all scientific congresses and all serious exhibitions at home and abroad bearing upon the optical products of the Zeiss Works. As an exhibitor the firm has aroused attention on many occasions by its new ideas and by the exceptionally high precision of its workmanship as well as by the consistent selection and arrangement

of its exhibits and the instructive demonstration of its products in the course of these exhibitions.

The articles of the Deed of Donation whereby Abbe founded the constitution of the establishment contains a provision to the effect *that the manufacturing establishment,* which constitutes the head and source of the entire foundation, *may not be removed from Jena.* Abbe placed a high value upon the original soil which bore the edifice erected by Zeiss and himself, and rightly so. But this did not exclude the erection of branch factories elsewhere, should this prove to be desirable or even necessary in the interests of the enterprise. Such branch works have actually been established in the mean time as the incidental outcome of the enormous expansion of the firm's business, and this happened in two ways. Branches have been established in foreign countries in the form of *branch* works and in that of distributing branches with attached repair workshops. Such branch works existed in Vienna for Austria, in Györ (Raab) for Hungary, in Riga for Russia, and in London for Great Britain. Those established at Vienna and Györ are still in operation. A factory was likewise erected some years ago at Saalfeld in Thuringia, not far from Jena, though so far this factory has not been requisitioned for the firm's own purposes. The firm holds also a controlling interest in other allied establishments, such as the Ica Company in Dresden, which has the largest European factory of photographic and cinematographic apparatus, the microscope works of the Winkel Company at Goettingen, and others. Other firms manufacture certain Zeiss goods under licence, thus Messrs. E. Busch, of Rathenow, for the manufacture of anastigmatic Punktal lenses, the firm of E. Krauss, of Paris, and Messrs. The Bausch & Lomb Optical Company, of Rochester, U. S. A., for the manufacture of photographic lenses, and so forth.

Distributing branches existed before the war at Berlin, Hamburg, Vienna, Paris, London, Milan, St. Petersburg, Tokyo, and Buenos Aires. After the war the firm's own branch depôts could be maintained at Berlin, Hamburg, Vienna, Buenos Aires and Tokyo only. In other countries it became necessary to establish distributing agencies which are more or less closely connected with the head establishment. Distributing sole-agencies in this sense have been established at the principal centres of the world market, such as London, New York, Paris, Milan, Madrid, Rio de Janeiro, Mexico, Calcutta, Shanghai, Melbourne, and so forth. This vast network of selling organisations, branches and distributing agencies now covers the entire globe.

All in all, we have had a glimpse of a complex organisation. But it is, withal, a well planned organisation, and it provides a necessary basis for the maintenance of the ever growing success of the undertaking.

A Ramble through the Workshops.

Before we shall have proceeded very far on our long proposed ramble through the workshops it will not be a secret to us that the site within the town boundary, over which the establishment has spread until it has formed entire streets of blocks, has long ceased to meet the undreamt-of development of the factory. And there are other considerations which promptly suggest the necessity of local expansion. As we naturally wend our steps to the source whence the whole derives its motive power or where that power is suitably transformed into conveyable energy, we find that we have to tramp for a good quarter of an hour until we reach the South Western end of the town; for the *steam power plant* which was erected in 1902 for the joint service of the optical works and the glass works is situated at the extreme end of the estate, upon which have arisen in growing impressiveness the plant of Schott & Co. Large as the plant would

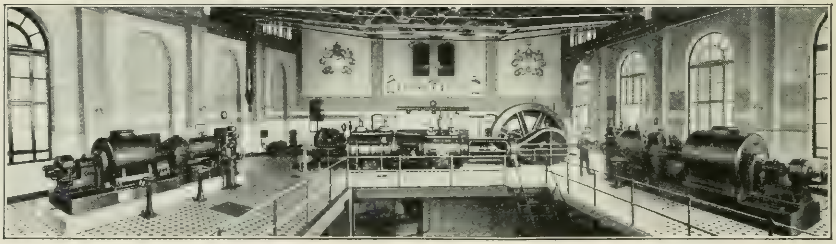


Fig. 223. The Steam Power House.

seem with its steam turbine capable of putting forth an effort of 6450 kilowatt, it has now ceased to meet the requirements of both the Zeiss and the Schott establishments. At present four water power stations, two in the vicinity of Jena, the other two in the upper valley of the river Saale, provide the reserve power, which in periods of coal scarcity and high prices become more and more valuable. Under normal conditions all these power stations are able jointly to furnish a considerable surplus of electrical energy to the supply system of the town and country area of Jena.

While the power plants considered so far provide motive power and lighting, a power house erected within the last few years, the *central heating station*, supplies the requisite heat to the whole of the office buildings and all the workshops. It is well known that this system greatly simplifies the working and that it effects considerable economies. It goes without saying that, in order to avoid undesirably long steam conduits, the power

and heating house requires to be situated in a central position. Actually, in the Zeiss Works it is situated within the boundary of the workshops. Incidentally it serves likewise as a substation for generating and transforming electrical energy.

The Zeiss Works is to a very large extent a property owner in Jena and the neighbouring villages. By the acquisition of a few estates it has become a prominent ground landlord. By this far-seeing policy on the part of the administrators it has become possible to meet within wide limits all requirements which have arisen and may arise in the matter of factory buildings or dwellings for operatives and other employees. The latter is a most important factor in view of the circumstance that owing to the intersected nature of the ground the available dwelling accommodation is always behind the demand. This is a state of things which can only be remedied very gradually and even then only by the efforts of co-operative societies and the municipal authorities. We shall have occasion to revert to this subject.

Fig. 224. Water Power Station at Burgau.

The materials required for the manufacture of the *optical products* consist principally of glass, and to a minor extent of certain crystals. As regards the latter it is no easy matter to secure from all parts of the world pieces of fluorite, quartz, calcspar, etc. of a kind which is suitable for optical purposes, and the stock of these crystals which has to be maintained represents a very considerable value.

To gain an insight into the making and preparation of the glass we shall have to betake ourselves to a suburb of Jena along the Lichtenhain boundary, where the Glass Works of Schott & Co., now forming part of the Carl Zeiss Foundation, spreads out in the true sense of the word. With its numerous buildings and chimney stacks, the power station, the gas works, the works railway, and the connecting line to the state railway, and, last but not least, with its gigantic mounds of waste fire clay and slag

the whole presents the appearance of a town in itself which imparts to the landscape a character of its own.

We begin with an inspection of the many raw materials which go to the making of the auxiliary substances and the many different kinds of glass which enter into their manufacture. The various raw materials are systematically stored in silos, like drugs in a chemist's shop. The number of containers conform to the number of different chemical components, from which, day after day, the mixtures are made up in exact accordance with definite recipes. In order to exclude the occurrence of errors in the weighing or to provide a means of subsequently correcting deficiencies

Fig. 225. A Pot Store.

or excesses, each weighing machine is fitted with a stamping register which enables the works manager to check each and every weighing. The individual components having been weighed into a box, the whole is tipped into the mixing machine, whence it is conveyed in trucks to the glass houses. The entire plant is fitted with provisions for the almost complete exclusion of dust, and what dust still remains is promptly withdrawn by powerful fans. Of the numberless raw materials which are here used we may instance the case of boric acid, which formerly came from Italy and America, but the greater part of which is now produced locally by a proprietary process.

We now enter the "pot" room. "Pots" are the furnace linings and vessels in which the mixtures undergo fusion. They are made of refractory fireclay and are prepared on the premises. With a good show of reason these pots have been described as the "soul" of glass making, for the quality of these pots exercises a decisive influence upon the nature of the resulting product. In the event of the fireclay not proving sufficiently refractory, the pot itself may undergo fusion or it may give and collapse. In the event of the pot being too porous the glass will creep into the pores and run out. Much also depends upon the chemical resistance of the clay since the acids of the glass components, especially silicic acid and boric

Fig. 226. Shovelling the Mixture into the Melting Furnace.

acid, though entirely harmless at ordinary temperatures, behave at higher temperatures as strong acids in the presence of the basic components. Conversely, glass with pronounced basic properties exercises a decomposing influence upon the fireclay, since in its chemical qualities the latter occupies an intermediate position between bases and acids. The illustration, fig. 225, shows a portion of the pot store for the optical glass section. It is interesting to note that the annual demand of this section alone amounts to about one thousand pots, each of which holds about a ton of crown glass or up to $2^1/_2$ tons of heaviest flint glass. The pots were formerly made, and are occasionally still made, by beating the plastic clay mass into a wooden mould and thus

forming it into a pot. By the later process invented by Weber the pots are cast like porcelain vessels. This method is based upon the colloidal liquefying effect produced by the presence of a small admixture of alkali.

We now come to the glasshouse proper, where day after day about a ton of material is turned into optical glass. The pot, before being charged, is preliminarily heated in a special oven during several days and finally fired hard at a higher temperature in the melting furnace itself. The mixture is then shovelled in (fig. 226), generally in company with a few fragments of the kind of glass which is to be produced. When the glass has entered the molten state, which occurs at about 1400 to 1500° C., the process of refining begins. During the continued fusion numerous gases escape in the form of large and small bubbles, and when this stage has been completed the mass is ready for moulding into the desired shape. The most interesting operation to the ordinary visitor is the process of drawing glass into tubes, which demands great skill and long practice. To an uninitiated onlooker it will seem something of a mystery how it is possible to draw from the liquid mass, without any measuring instruments, a cylindrical tube of prescribed bore and thickness. To begin with, a conical wad of hot glass, hollow within and of the consistency of wax, is seen to hang from the blow-iron with which it was blown, but at the appropriate moment another glass blower takes it up by a glass dish, the so-called pontil. The two glass-blowers then proceed to walk in opposite directions and, in so doing, draw the glass tube into a kind of hose pipe, which at first hangs in the air but subsequently, with extending length, rests upon a wooden run-way placed in readiness. Here it stretches out in a straight line and, rapidly cooling, furnishes the required tubing. An identification mark, which differs with the nature of the glass, is rolled into the side of the initial cone and drawn out together with the latter.

The production of optical glass occupies a special position, as in this case the glass is moulded into the form of thick rectangular slabs. In order to achieve the utmost degree of homogeneity the mass is kept in motion by stirring, and this process has now been perfected to such an extent that at least a considerable proportion of the ultimate product is optically sound. At the end of the stirring process the pot is withdrawn from the furnace and transferred to the annealing oven, where it remains for a week or longer. During this treatment the severe contraction of the glass and its adhesion to the sides of the pot unavoidably cause the mass, together with the pot, to break up into pieces. These are formed into slabs of different shapes and sizes. This is likewise done in fireclay moulds by allowing the glass to "flow" at a temperature which is not high

enough to render the mass liquid but yet high enough to soften the mass sufficiently to let it sink completely into the mould. Even then, this moulded mass is not yet fit for transformation into optical instruments. It is fairly homogeneous but cannot be relied upon to be isotropic; that is, it still retains properties of a crystalline substance, and, in particular, it is liable to exhibit double refraction. This defect is removed by very slow annealing, that is to say, by a process of cooling which begins at about 500 to 600° C. and thence is continued downward so slowly that any stresses which may arise do not endure to produce strains. As a rule, the process is continued for a month, in the case of large pieces even for several months. This process could not be brought to its highest degree of perfection until electrical heating provided a means of regulating the temperature within the annealing stove in very minute stages. As a matter of fact, great advance has been made in this respect in the Jena glasshouses. Another difficulty is occasioned by the formation of bubbles and by the inclusion in the mass of foreign substances, such as globules of lead. Here, however, the deciding question is mainly whether these bubbles impair the optical qualities of the glass, which is frequently not the case, since light has always an infinitude of paths open to it, while it is only the total optical effect which becomes manifest. Fraunhofer, the founder of modern astronomical optics, therefore hit the nail on the head when he met a refusal to accept a lens which contained bubbles but was faultless in its optical performance by retorting that lenses were made to look through and not to be looked at. It is, on the other hand, extremely important that the glass should be free from so-called striae or portions having anomalous refractive properties. Indeed, it may be said that the fight with the striae by dint of extreme care in the preparation and further treatment of the mixtures constitutes one of the chief elements in the whole business of making optical glass.

Glass masses receive individual treatment where they are required for making very large lenses and mirrors for astronomical telescopes, and this applies also to pieces which are required for particularly exacting scientific purposes. After their withdrawal from the furnace they are poured into appropriately formed moulds. For instance, in the case of telescope lenses these moulds take the form of a spherically curved dish, so that the resulting slab is convex on one side and flat on the other for further mechanical and optical treatment at the Zeiss Works or elsewhere. The pouring out of such a great mass of white-hot glass for the casting of a giant lens is a magnificent spectacle, but it is also a procedure which demands the most exactingly systematised cooperation of all concerned in it, if a faultless result is to be achieved.

The slabs of glass as they issue from the glasshouse are not transparent, since their surfaces are more or less rough and puckered. They are therefore sent to the grinding shop, where they are roughly polished on two opposite ends so as to render them transparent in that direction. To expedite this procedure several plates are cemented together by means of plaster of Paris so that the surfaces which are to be preliminarily polished may be in one plane. The entire combined surface may then be ground and polished in one operation with sand, emery and rouge. Large lens discs and prisms only are prepared in a separate grinding and polishing shop and subjected to a much more refined process of preparation. The object of the inspection and optical examination through the polished end faces of the slabs of glass is to ascertain whether and to what extent the glass is homogeneous and isotropic. The presence of a strained condition in the glass betrays itself by the appearance of colours due to polarisation (fig. 228), double refraction, etc. No plate is passed on for further treatment until it has been found in the testing room (fig. 229) that it is in a faultless condition.

Fig. 227. The casting of a large lens in the glasshouse. From an ink drawing.

One of the most important sections of the glass works, as regards extent and output, is that concerned with the manufacture of lighting implements, especially cylinders and other glass bodies for incandescent gas light and electrical light. The distinguishing feature of the material produced in this section is its thermal resisting qualities, which protect it from cracking when

exposed to sudden and violent changes of temperature. The somewhat higher initial cost of this article is therefore more than fully repaid by its far greater lasting qualities. The same applies to a speciality for scientific and technical purposes, which comprises all kinds of utensils of the nature of boiling flasks, beakers, test-tubes, and so forth. This special glass, known as *laboratory glass* is an invention the value of which cannot be rated too highly from the point of view of the chemist. In one special form this thermal glass bears the distinctive name "Suprax Glass". In its thermal properties it is much more closely related to quartz glass (fused quartz) than ordinary glass.

Fig. 228. Strained glass.

As we proceed on our journey through the works we shall not fail ere long to be impressed with the diverse nature of the operations conducted within its boundaries. We must content ourselves with a hurried glance at a few important and interesting products. Thus we notice barometer and thermometer tubing made of a glass which differs in a certain way from ordinary glass. The latter is subject to secular elastic changes and in the case of thermometer tubing exhibits a most undesirable quality known as the depression of the zero point, which vitiates the

Fig. 229. Testing the glass plate.

accuracy of the thermometer readings. The Jena glass is entirely free from this quality and is therefore permanently reliable. To meet the requirements of the electrician special kinds of glass are now produced as the result of recent successful endeavours which have remarkable insulating properties or an exceptionally high dielectric constant. This is a quality of paramount importance in the construction of condensers, especially in relation to wireless telegraphy. How immense are the contrasts between the properties of these different kinds of glass may be gathered from the fact that, whereas glass is popularly reckoned among the specifically light substances, glass material is to be found at the Jena Glass Works a block of which of the size of an ordinary brick can only be lifted with the utmost effort.

In conclusion we may mention a few specialities, some of which have attained great importance as an item in mass production, viz. the Stia ampère meter for recording the amount of current supplied by the companies to a consumer. This is based upon a very interesting electro-chemical process and is free from the majority of objections to which other current meters are subject. Among other specialities are to be found a new mercury vapour lamp, coloured glass with various special properties, and many other things.

We will now leave the glass-house and wend our steps towards the optical workshops. Embarrassment greets us as we enter. We may indeed not proceed without a plan to guide us. Without it our ramble along its vast chain of activities would procure us nothing better than a fatiguing sense of bewilderment and astonishment. A glance at the plan of buildings which will be found at the end of the book cannot fail to give us some impression of the mass of buildings which we are about to explore. On one side of the Abbestrasse lofty buildings form a square of streets such as would be regarded as imposing in a modern city, and beyond these new blocks are rising on a like scale. The number of older buildings which remain as witnesses of the "brick period" is steadily diminishing. One after another is making way for modern giant buildings, cast, as it were, in one piece of reinforced concrete. There they stand, a cynosure to the distant eye, monotonous masses of grey, yet capable of uttering a charm of their own.

How are we to find our way through this mass of buildings, five, six, and twelve storeys high? In a sense we are to be congratulated on having before us an imaginary journey instead of an actual tramp through miles of workshops. We need not, therefore, consider with the seriousness which behoves a tourist such matters as time and comfort, and we are quite at liberty to take the sequence of the stages of manufacture and the nature of the resulting products as the milestones and wayposts of our itinerary.

In particular, it will be sufficient for us to follow the roads whence we can obtain a glimpse of the processes by which materials are selected and prepared and of the manufacture and ultimate disposal of the numerous products of manufacture, and incidentally we shall be able to note a great variety of mechanical and optical processes.

Proceeding on our pilgrimage with this idea in view, the first section which we enter is that of the glass cutting workshop, where the slabs of glass as they come from the glasshouse are cut into plates or prisms by means of rotating discs of sheet iron. The peripheries of these discs are notched with a hack knife and charged with diamond dust. Petroleum is used as a lubricant, and usually one of the edges of the cut plates is smoothed and roughly polished to prepare them for optical examination. This takes us to the *lens and prism grinding shops,* for these are naturally two of the principal forms of glass bodies which are used in the construction of optical instruments, the third important element being the reflecting surface or mirror. This stage of the process embraces elements varying widely in the matter of dimensions and form of the lenses and prisms which are required as parts of the many hundreds of different instruments made in the vast establishment. Naturally, these operations demand many extensive and variously installed workshops equipped with machines widely differing in design, size, and detail. For it must be remembered

Fig. 230. Glass Cutting.

that lenses are here produced ranging in diameter from a single millimetre to a metre, that is from the $^1/_{25}{}^{th}$ part of an inch to a matter of 40 inches. The small lenses are luted upon hemispherical grinding chucks and ground with the aid of a corresponding hemispherical tool and quartz sand or emery as an abradant. In the case of the large lenses the grinding tools are likewise parts of spherical cups of various sizes. An idea of the wide range covered by this section may be gathered when we are told that the tool store contains over 20000 *grinding tools* with about seven hundred different radii of curvature.

After these various glass components have passed through all the processes by which their surfaces are prepared and ground in this section, they proceed to the *polishing shops,* where they undergo the final and most exacting finishing operation. Lenses with very pronounced curvatures are polished separately, while lenses with flatter curvatures are always polished in batches of several, in some cases of as many as fifty. They are then luted in chessboard fashion upon a more or less spherical base, upon which all are pressed down into the matrix so as to form a single large spherical surface of the appropriate curvature. In the special case where plane surfaces are to be produced, as with prisms and plates, the base upon which they are luted is naturally flat, but it must not be supposed on that account that this is a specially simple case; on the contrary, the production of a rigorously plane surface is an exceptionally exacting procedure. The polishing discs and the corresponding polishing tools are kept in motion by electric motors, and the chuck with its collection of ground lenses or flats is held in contact with it either by hand pressure or automatically, and is likewise kept in rotation. The primary object of the two rotary motions is to impart to the spherical surface a uniform curvature in all directions. Where this spherical condition has been attained the two bodies in contact can be rotated relatively to one another, so that the movement may be likened to that of a point on a rolling and pitching ship. Much experience and skill, however, is needed on the part of the controlling operator to ensure a uniform curvature, to obtain which he must know how to vary and when to interrupt the pressure, etc.; but if he possesses that skill he is as well able to achieve an equally perfect result by hand, especially where small lenses are concerned, as with the mechanical arrangement. It will be readily understood that in the case of non-spherical lenses, which are now made with a certain measure of practical success, the advantages which result from the angular motion of the axes of rotation of the lens and the grinding tool must necessarily be sacrificed. This renders their production much more difficult, more laborious and costly. As a matter of

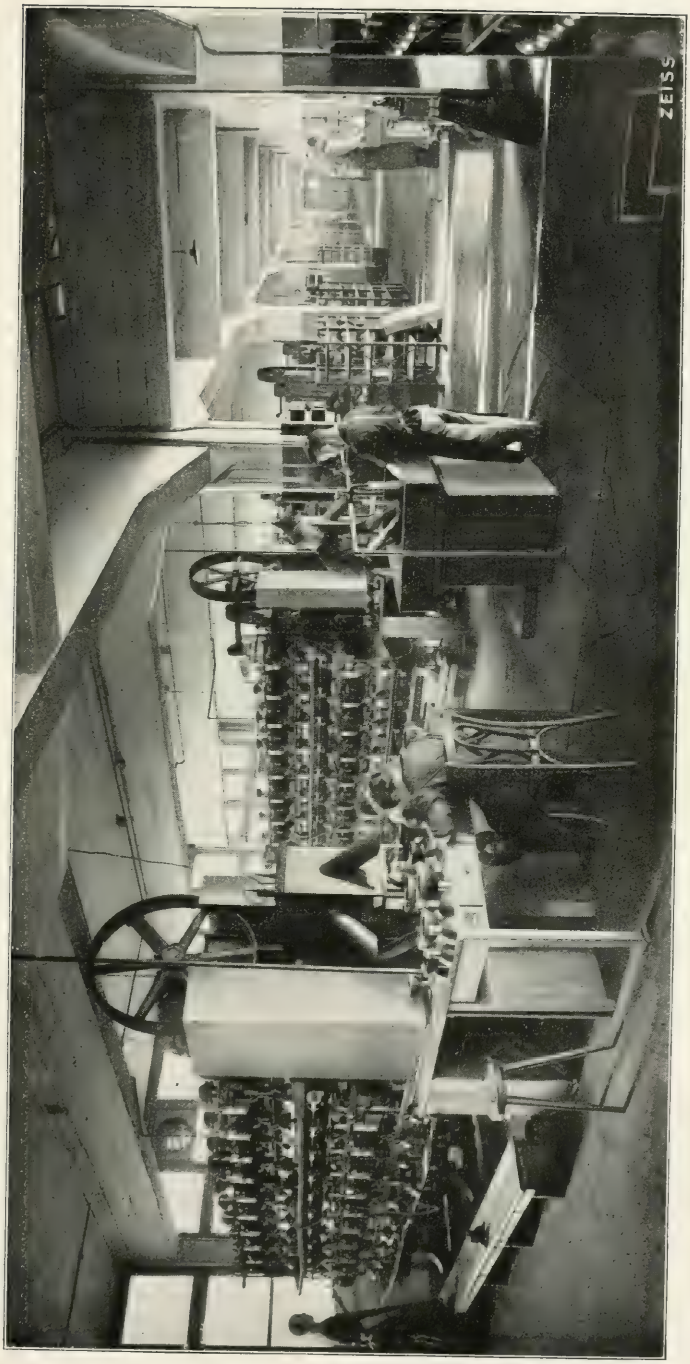


Fig. 231. Polishing Shop for Spectacle Lenses.

fact, during the process of producing spherical lenses and flat surfaces the operator requires to check his progress and the quality of the required surface at all points. As already mentioned, this is done by the Fraunhofer-Löber method with the aid of *Newton's colour rings*. The appearance of these interference rings between the surfaces in being and a mathematically exact control surface having the opposite curvature of like radius (i. e. a convex lens surface to test a concave surface and conversely) furnish a very exact means of checking the degree of accuracy of the surface. Since an interval from one colour ring to the next indicates a difference of a fraction of a thousandth of a millimetre in the thickness of the film of air

Fig. 232. Testing the quality of the polish under a magnifier.

between the test glass and the work surface it will be realised that by causing the colours to vanish by polishing away the excess indicated by the colours a degree of exactness is attainable of which we are scarcely able to form any conception. This degree of exactness accounts for the exquisitely sharp images which result when these surfaces perform their function in telescopes, microscopes, or photographic lenses. Naturally, such exactingly finished surfaces are comparatively costly to produce. Thus, a single small lens often requires to be worked hours together before it satisfies every requirement, and to the cost of this work must be added a certain portion of the overhead charges. Since some of these smallest lenses weigh only a fraction of a grain, a pound weight of them would run

into a quarter of a million pounds sterling, that is to say, several million times more in value than the equivalent quantity of unworked glass. This then represents the ratio in which a material of small monetary value has had its value enhanced by the application of ingenious skill and labour. It goes without saying that this section is provided with a noble collection of trial glasses, and these again have been obtained by reference to scientifically produced standard glasses, so called although, as a matter of fact, they consist of quartz, which is much harder and incidentally also much more costly where large and flawless pieces are concerned.

Our ramble trough the optical section would be incomplete if we were to omit to pay a visit to the section where large mirrors are made, such as form part in the construction of reflecting telescopes and searchlights. The high prices of good and optically plane mirrors are a sufficient indication that their manufacture is a costly business, and from this may be gathered the much greater difficulties which are encountered in the production of mirrors of a spherical, and still more so of paraboloid or spheroidal profiles. Yet it is just these which constitute our most perfect means of obtaining sharply defined optical images. As we have already indicated in a previous chapter, mirrors of this latter kind often involve in their production very meticulous operations, such as the removal by grinding of zonal portions of the surface, the depth of which may not exceed fractions of a millimetre or even of tenths of a millimetre, and, moreover, these zonal departures from the true sphere require to be mutually adjusted with the most exacting precision. In these circumstances it is no wonder that the completion of a giant telescope mirror is often protracted through many months, and it frequently happens that a seemingly finished piece of work requires renewed working, in consequence of which the ultimate cost becomes very high. In the case of the projector mirrors on the other hand, the material requires to be ground down to a much greater depth, and this in its turn has necessitated the elaboration of special methods.

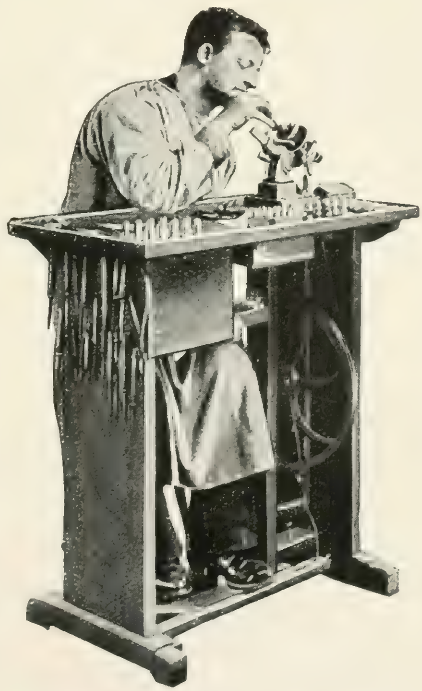


Fig. 233. Mounting very small lenses.

Fig. 234. Showing the various stages by which the raw glass is converted into prisms and lenses.

We will now quit the purely optical section, and in so doing we invite the reader to bestow a parting glance upon the preceding illustrations from fig. 229 onwards, which give an idea of some of the many operations involved, while fig. 234 illustrates the entire genesis of prisms and lenses from the unworked glass to the finished article. However, as we proceed on our journey we shall naturally revert to these finished components, but meantime we must retrace our steps to another primary source of materials.

Much in the same way as the optical sections derive their raw material from the affiliated glasshouses of Messrs. Schott & Co., so the metal working sections take theirs from the establishment's *own foundry*. Large iron and steel castings only are put out. The foundry receives its raw material from the supply stores, upon which also devolves the task of storing and distributing prepared parts and finished components, and it delivers its castings to the unfinished stores section. The metals which are mainly used for making up alloys are copper, tin, zinc, iron, and *aluminium*. Since in a great many of the instruments and apparatus made at the Zeiss Works portability, or at least movability, play an important part, it became imperative to economise in weight as much as possible, and naturally aluminium stands out prominently in this respect in view of its low specific weight. Unfortunately, this metal has several qualities which stand in the way of its unrestricted use. On the one hand, it is too soft, on the other too brittle, and, moreover, it leaves much to be desired in the matter of durability. After protracted and at first unsuccessful experiments processes have been discovered for producing serviceable alloys with this metal as the principal ingredient. For progress in this direction we are mainly indebted to the metallurgical application of electrolysis. Formerly the price

Fig. 235. Optical Polishing Shop.

Fig. 236. The Foundry.

of aluminium bore quite an exorbitant relation to the cheapness, one might say, worthlessness, of the initial material, that is, the alumina and clay which makes up an immense proportion of the earth's crust. The electrolytic method of extraction, however, has brought down the price of aluminium to a level which is little above that of copper. The foundry has naturally associated with it a moulding shop, where the moulds are formed from an immense number of different patterns. Long before aluminium had come to be so widely used as it is now in the construction of aircraft, and elsewhere the Zeiss foundry was one of the largest and most perfectly equipped light-metal foundries in Germany.

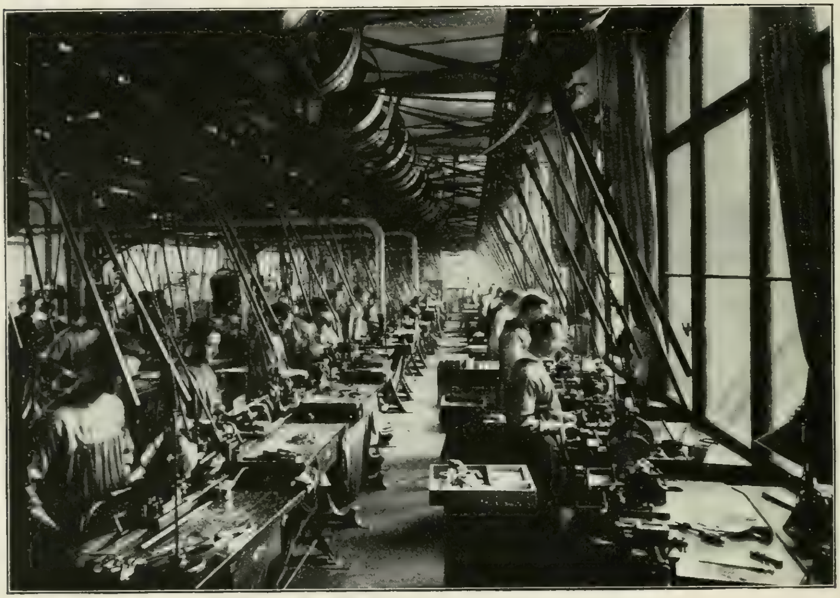


Fig. 237. The Turning Shop.

From the stores the castings pass on to the *turning and milling shops*, where they are machined up to the required point. The workshops set aside for field-glasses constitute a particularly large section. In view of the exceptionally large number of field glasses, which are to be turned out to cope with the enormous annual demand plant has been set up by which manufacture can be carried out on the grand scale. It includes lathes and milling machines capable of operating in up to six stages. In these machines automatic working has been specialised to such a refined degree that three of them may be controlled by one operator. By this

means considerable economies are effected in cost, and this in its turn exercises its influence upon the price or the style and finish of the instrument in question.

After the return to the store department the machined parts wander for the second time into the various sections with which we have become acquainted in our first survey of the specialising works departments; that is to say into the microscope, projection, photographic, astronomical and terrestrial telescope, and other departments. The whole of the machining which the metal parts undergo is done according to drawings and gauges, and after each operation they are controlled by the respective foremen or viewers before they are passed on to the next stage as satisfying all requirements within the given tolerance. Special procedures are naturally adopted in the case of *new designs,* and the same applies to special orders. These are received by the establishment in large numbers throughout the year, more especially from scientists both for research work and teaching purposes. Although these orders frequently offer only the barest prospect of covering the cost of manufacture, they are willingly accepted if they do not altogether exceed the scope of the establishment, in view of their suggestive value. All new designs of this kind, when worked out in principle and in all their essential features by the members of the scientific staff, are then elaborated in detail in the drawing offices, and not until these drawings have been approved of is the actual work of construction proceeded with in the respective works departments. It would far exceed the limits of our survey were we to attempt to pass in rotation through all the departments and in each review the great variety of operations which are there carried out. We must be content to let a few examples speak for the whole.

To begin with, let us throw a glance into the *microscope adjusting room.* Here the finished objectives and eyepieces as well as the completed microscope stands are delivered for making up an optically and mechanically perfect whole. Apart from the metal mounts of the lenses, their screw connections, etc., one of the most important elements of adjustment is an absolutely exact centration of the lenses which go to form the complete optical combination, and we have already learned that in some cases such a combination is made up of a good many lenses. All glass elements and metal parts require to be brought into a very precise relative position to one another, and every time an element is adjusted the preceding adjustments have to be verified to ensure the ultimate perfect adjustment of the whole. When the last finishing touches have been applied in the matter of polish and cleaning, etc. the microscope is ready to leave the establishment.

Turning to the *field-glass* department, where the glass prisms are mounted in their casings of aluminium alloy, we may watch the process whereby these casings are lined with vulcanised rubber. This is done by means of special machines which control every smallest detail in the process. Next, the optical parts are cleaned, mounted, and adjusted, the focussing devices, either midway between the two telescope bodies or separate for either eyepiece, are then appended and the whole finished in every detail. Special care is exercised to ensure perfectly dustproof and watertight joints. To this end the mounted field glasses are placed under a shower-bath and special removable tubes are applied to carry out the test. Thanks to the scrupulous care with which this test is carried out all the field-glasses which pass out of the establishment are absolutely dependable, so much so that they are safe for use in the tropics and, indeed, wherever it is not practicable to deal over-gently with them. As in many industries, the manufacture of field-glasses has to reckon with the climatic and other conditions as they exist in all parts of the world, and this has naturally intensified and complicated the requirements which have to be satisfied.

An imposing aspect is presented by the spaces controlled by the *Astro Department.* Here astronomical telescopes are built up, mounted and completed in every detail, including complete observatory domes for their reception. As we have already had occasion to point out, experience has shown that in order to successfully fulfil all the requirements which arise in a complete telescope installation it is essential that the constructor of a telescope should be entrusted with the design and construction of the entire observatory so as to establish complete conformity throughout the entire installation. The astronomical department undertakes the construction of domes of largest dimensions, and, as is usual at the Zeiss Works, little homage is paid to the imperious voice of tradition. The Zeiss domes are not copies but independently created designs embodying modern principles and carried out with modern resources. Fig. 240 on page 205 gives us an idea of the appearance of the telescope erecting shop when such a giant telescope as the reflector which was completed in 1914 for the new observatory at Neubabelsberg is in course of erection. This telescope measures 46 feet in length overall, and the actual tube is 39 feet long. These dimensions may give an idea of what its weight is like, and yet its ingenious devices and perfect workmanship enable the observer to cause it to move in all directions with scarcely perceptible resistance, in which electrical motion devices play an interesting part. The object glass of this telescope with its diameter of 25 1/2 inches, its focal length of 34 1/2 feet, and its mass of about 5 hundredweights, is the result of a vast expenditure of time and

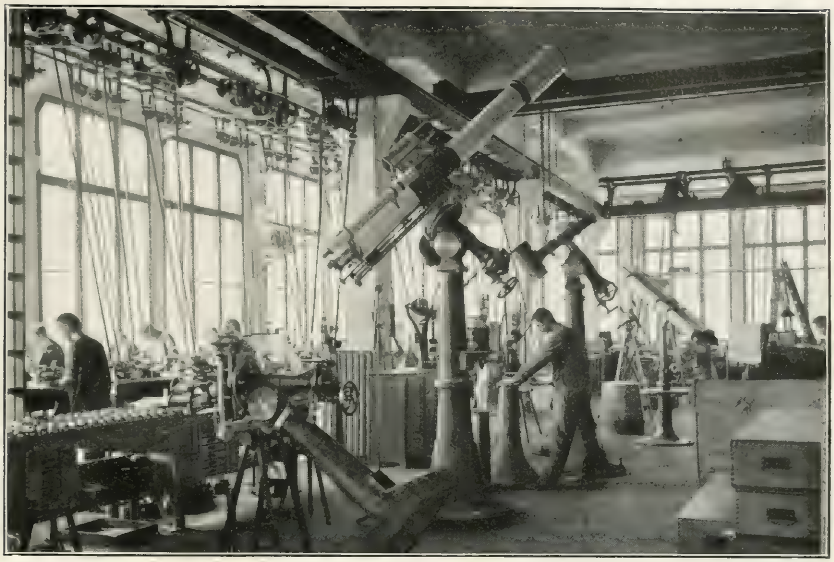


Fig. 238. Fitting shop for astronomical telescopes.

effort, as will be readily gathered from what we have already said. In addition to this erecting shop for large telescopes there is a large shop for fitting up smaller telescopes of every kind, including the popular view telescopes, special instruments for the observation of solar eclipses, and a great variety of other telescopes.

Allusion has been made to the principle according to which, wherever circumstances admit of it, the astronomical department much prefers to undertake the construction of an astronomical installation in its entirety. In other branches a similar principle is in force, especially wherever work is undertaken, exclusively or mainly, on behalf of public bodies. Accordingly, instruments such as those designed for land surveying and higher *geodetic surveys, sighting telescopes,* and *range-finders,* are supplied complete with all appurtenances. A visit to the shops where the range-finders or telemeters are made will prove particularly interesting, because this section, like the Astro Department, is concerned with instruments ranging from hand size to giant dimensions. The largest of these scarcely present the appearance of instruments, being far more suggestive of machines, and externally they already betray their ultimate destination on fortresses and on war vessels, for obviously when used for military purposes, the utility of the instruments depends as much upon their rigid and compact design

and their extreme simplicity as upon their optical perfection. These instruments attain a length of some thirty feet, and, in consequence, they are capable of furnishing extremely accurate readings at distances up to 8 1/2 miles. All the same, they can be operated with the utmost ease.

On the other hand, there are other departments where the establishment confines itself to the supply of the optical portion. In these cases the establishment does not enter into direct relation with the public but deals with the manufacturers and dealers only. This has notably proved advisable in the *photographic department,* which confines itself to the manufacture of photographic lenses. The *spectacle department* likewise supplies its products to the ultimate user through intermediate channels only. In view of the fact that spectacle lenses, including the specially exacting Punktal lenses, no less than the spectacle frame require to be carefully determined to suit each individual case, the Zeiss spectacle lenses are sold by experienced opticians only.

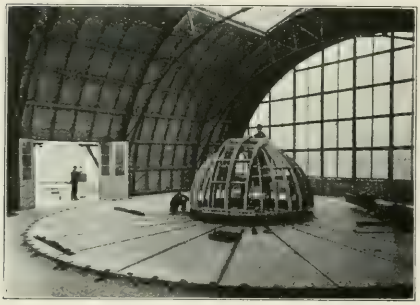


Fig. 239. Erecting Shop for Observatory Domes.

Having wandered through the principal sections of the optical and mechanical departments we come to the *auxiliary works sections* which supplement, as it were, the range of operations at the beginning and end. At the beginning assistance to the main business of manufacture is given by the *mechanical engineering section,* the establishment of which had proved an imperative necessity. It goes without saying that the bulk of the machine tools and motor plant have been obtained from makers specialising in such machines. But apart from these, there are many machines of such a highly specialised nature that outside firms do not willingly undertake their construction, if indeed it is practicable to do so satisfactorily excepting by those intimately acquainted with the processes in question. A rough idea of the significance of this section may be gathered from the view of the large engineering shop of which fig. 241 gives a partial view. It will also be seen that this shop has to cope with a great variety of machine designs serving a wide range of purposes. Such a progressive system as that ruling at the Zeiss Works naturally is faced with the necessity of continual modifications of existing designs and the addition of new machines.

Then there are such auxiliary sections as the *wood working department,* the annual timber store of which has an average value of £ 15,000 and

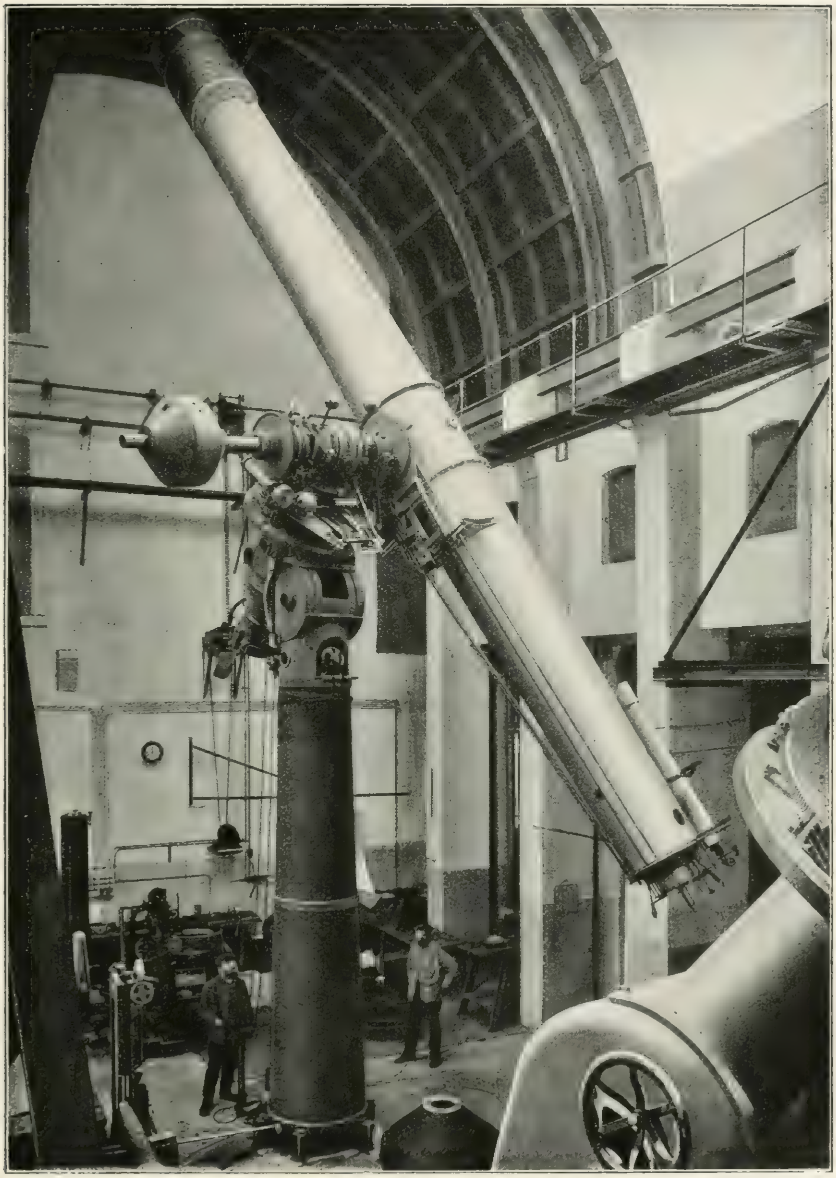


Fig. 240. The 650-mm. (25-inch.) Refractor of the Observatory of Neubabelsberg, as it appeared in the erecting shop.

Fig. 241. Engineering Shop.

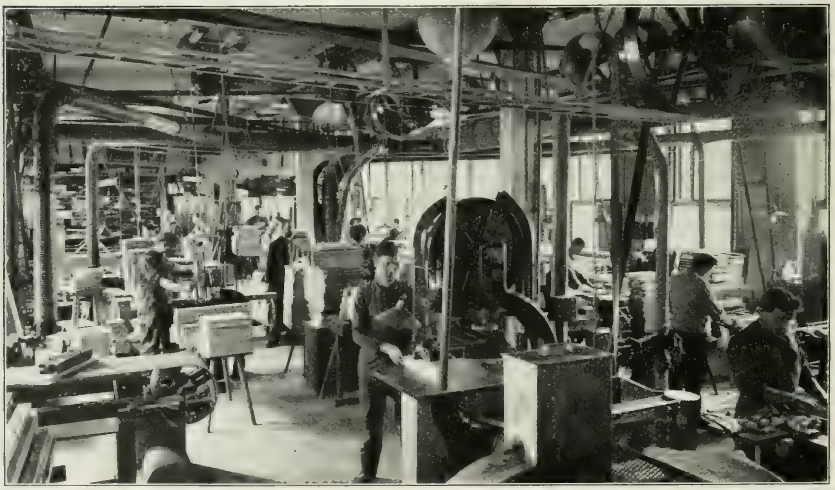


Fig. 242. One of the eight Wood Working Shops.

which embraces all kinds of indigenous and foreign wood. This department is sufficiently large to employ about 150 hands working with 82 machines. Its main function is to turn out fitted instrument cases for microscopes and surveying instruments, range finders, also tripod stands, photomicrographic cameras and other wooden accessories. Amongst the other subsidiary workshops we find the *sheet metal workshop,* which is equipped with the latest types of machines for cutting, moulding, and jointing sheet metal; next, a lacquering shop, engraving shop, the dividing engine rooms for the graduation of gauges of the highest degree of precision and, finally, a very extensive *leather workshop,* where the cases for

Fig. 243. The Leather Shop.

field-glasses and those for many military instruments, microscope travelling cases, lens hoods, and other articles are made. In this latter section may be seen in operation several leather slicing machines, which will cut the raw leather into thinnest sheets, also gilding and embossing presses, wire threading machines, riveting machines, stamping machines of every kind, and numerous sewing machines. Though only auxiliary in relation to the establishment, this leather working department alone will bear comparison with many notable leather works whose sole business it is to turn out leather work.

Fig. 244. View of a portion of the principal business office.

Fig. 245. One of the principal drawing offices.

The terminus of our long journey, which we have abbreviated into these few preceding paragraphs, is the Head Office, which embraces all that concerns the scientific, technical, commercial, and administrative activities of the establishment, in fact, everything that is not actual manufacture. The various offices are accommodated in two buildings, the older corner building in the Zeiss and Abbe Streets, which by its style and the use of red bricks declares itself to be the older of the two, and a large new structure of reinforced concrete. Both are connected to form a single block. The entrance leads into a reception hall, which gives access to a number of showrooms in which a collection of finished products of the works at once demonstrates the wide range of manufacture. After these follow the offices occupied by the heads of the management and of the scientific departments together with the requisite board rooms, laboratories, and calculating offices, all distributed over the various floors. This portion accommodates also the photographic studio, whereas the rooms for experimental work in projection and photo-micrography are to some extent situated in the basement. The most imposing features of this building are the two large halls which respectively constitute the *principal business office* and the *chief drawing office*. The former has a length of about 320 feet and affords accommodation with excellent light for two-hundred clerks, while the drawing office with its fixed and movable drawing tables is occupied by a large number of technical specialists and draftsmen, who here work out general designs and prepare working drawings of all that is new. The building is surmounted by an *observatory dome* (as shown in fig. 51 on page 63), which ranks on an equality with many an observatory of note and is equipped with a 12-inch. refractor of 16$^1/_2$ feet focus for experiments, trials, and tests, also with astro-photographic cameras for very large plates, a standard time indicator with a wireless time receiving station and all necessary appurtenances. A strikingly elegant feature is the mechanism for turning and opening the dome. Stepping out upon the roof, we obtain an excellent survey of the buildings of the Zeiss Works, especially of the various roof towers. These serve special purposes, such as experiments with searchlight projectors, which on many nights present a fascinating spectacle as their beams play into all directions, rotating, dipping, contracting and expanding. The whole of the town of Jena with the surrounding heights can be surveyed from this roof, for, as rarely happens to be the case, this great establishment which is the governing factor in the town's life, has retained its central position in a local as well as economic and ethical sense. Proceeding from this centre the town sends out twigs in all directions, and a large proportion of the houses which from this elevation are seen to stud the

outlying parts of the town are occupied by people whose daily life is spent within the precincts of the Carl Zeiss establishment. One is reminded, though on a smaller scale, of the conditions as they exist in the world of Krupp at Essen.

We now descend to visit three other parts of the building, the patent office, the library, and the telephone exchange. We shall have occasion to revert to the *patent office*, but for the present it must suffice to say a few words about the rapid development of this department. It is interesting

Fig. 246. Micro Inspection Room. Final examination before despatch.

to note that, while in Abbe's days it was an insignificant appendage, it is now an important and well staffed department, for upon its members devolves the task of searching the patent literature of all countries of the world and to prepare the patent specifications and claims of the home inventions in the leading languages of the world. The mere sight of the mass of patent literature which has accumulated in the course of the years shows with overwhelming eloquence to what extent the once timidly silent optical industry has been forced into the arena of fierce competition. The large hall which contains the *library* of the establishment cannot fail to fill the beholder with astonishment. There are certainly few industrial establishments which possess such a store of learned material. We find here long

rows of journals devoted to optics, physics and various branches of technology, also military, medical, sports journals, and many others. The principal works on all subjects are available for reference and for exhaustive study, and a carefully compiled catalogue is there to bring out the full value of this large collection of literary material. Finally, we come to the *telephone exchange*. The significance of this station is not difficult to comprehend when one thinks of the enormous number of connectedly working persons, all spread over a wide area, who must necessarily keep in verbal contact, able to exchange inquiries and obtain prompt replies. Obviously, in an undertaking of such dimensions personal visits from one section to another are more or less out of the question, for in most cases this would necessitate a veritable little journey, and, moreover, a personal call might often enough occur at an inappropriate moment. The entire establishment is therefore transfused with a network of telephone wires, and the whole system operates automatically, so that without human intervention one thousand individuals can be placed in communication, everyone with every other person. This is done by giving three turns to the now well known perforated pallet in conformity with the three figures which constitute the number of the person called up. A brief stay in the office of a subscriber will soon prove to a casual visitor that the arrangement is a practically never ending necessity. Calling and being called up alternate continually, and it is no exaggeration to suggest that the daily number of conversations vary from ten to twenty thousand. One smiles, though certainly not irrevently, when one thinks of the days when Carl Zeiss would have had no use for the telephone, had it existed, since he and his one assistant worked within a few feet of one another and were always able, and indeed compelled, to confide to each other by word of mouth what little was to be communicated.

And now we may conclude our imaginary ramble through the works. Actually performed, the journey would occupy at least four hours, if one is satisfied with a superficial glance at things, whereas eight hours would be needed to view the whole with something approaching technical intelligence.

It may be added that such conducted tours through the establishment are now only instituted in exceptional cases and only after a definite plan and at certain times and again only after personal application, and in these cases the visitor is conducted, as far as practicable, in accordance with a program suiting his special wishes and the subjects in which he is particularly interested.

The Question of Ownership.

To a description of an industrial undertaking it is usual to append a brief survey of the social conditions under which it thrives and especial interest attaches to the provisions which exist for the betterment of the workers, and employees in general. In the case of the Jena establishment the chapter which deals with the social aspect is fully as significant and interesting as the review of the productive side of the establishment. For there is no doubt that its social organisation is no less an achievement of the profoundest interest to the sociologist than the quality of its products is accepted as a standard throughout the world. Indeed, were we to measure the space which should be allowed by the interest which it is likely to awaken in wider circles its space allowance should by far exceed that accorded to the preceding section. After all, optics remains optics, and without it life would still be conceivable on this planet of ours. But whether this selfsame planet will be able to continue much longer in its industrial life without a system of social organisation which fully accords with the actual and fearlessly understood conditions of civilised life is a mightily different question. The organisation of the Zeiss establishment is at least an example and perhaps a model worthy of the most serious study.

For nearly thirty years, from 1846 to 1875, Carl Zeiss, the founder of the optical works, was the sole proprietor. He continued to occupy this position for some time after his cooperation with Abbe had begun to show tangible results. When, however, these successes forced upon him the necessity of successively extending the undertaking and sinking into it the necessary capital, Zeiss had naturally to devise means of permanently attaching his associate to his undertaking. It would be a one-sided aspect of the position to suppose that Zeiss took Abbe into partnership *solely* to give expression to his grateful appreciation of his meritorious achievements. No doubt, such motives did prompt him, but it is equally true that Zeiss was impelled by another and, let us add, perfectly reasonable motive, which was to make Abbe a participant of future risks.

From 1875 onwards Carl Zeiss and Ernst Abbe were joint owners of the optical works. In 1881 the eldest son of the former, Dr. Roderich Zeiss, entered as the third partner. We need not fear that we are committing an indiscretion likely to hurt anyone's feelings if we frankly state that Abbe and Roderich Zeiss were scarcely men who had been destined to pull together. Apart from details, their aspects of life and of the world in which they lived were distinctly opposed. In fact, had it not been so, we should not have had any occasion to expatiate in the first pages of this book upon

the rare circumstances which in the persons of the elder Zeiss and Abbe brought together two men who were just moulded to unite forces. The inevitable was bound to come, and so it happened that barely a year after the death of Carl Zeiss (1888) Roderich Zeiss withdrew from the management and actually retired, informally at least, from the business. Abbe thus became, as it were, the captain of his ship, and the reader may now feel entitled to hear of many deeds by which Abbe asserted himself as captain and monarch. However, if the reader expects a tale of stirring deeds he will be disappointed, for the soil tilled under this brief autocracy has brought forth one solitary fruit, but one so costly in its ripeness that it trascended the best that could have been dreamt of under the leaden-grey sky which frowns upon modern industrial existence. And this fruit is now given to thousands to pluck without stripping the tree whereon it grows. This fruit is the *Carl Zeiss Foundation* which Abbe has called into being, naming it after his departed colleague, and to which in 1891 he surrendered by a deed of gift his proprietary interests in the optical works and his rights as a partner in the glass works.

The Carl Zeiss Foundation.

If man were endowed with an unlimited existence, if only in a sense which justifies the assumption that succeeding individuals will maintain in action a continuous series of intellectual and moral principles in an unbroken chain, the ideal government of an industrial undertaking of whatever kind would doubtless be one based upon personal conduct and responsibility. Personal will has this in its favour that it can always be exercised with freedom, and, if it rests upon a good intellectual and ethical basis, its exercise will accord with the needs created by changing circumstances. As contrasted with this exercise of individual will a directorship of an undertaking subject to the provisions of a legal document or charter is denied freedom of action and is therefore imperfect.

Unfortunately, the conception of the continuity of being is an abstraction of the mind. Man comes to an end, not only personally, but with him also vanish his will and his power of action. The son already differs from his father, how much more a stranger who may take the place of a predecessor. Personal conditions and developments are quite incalculable in their nature. If therefore an ever so perfect charter cannot achieve what may be accomplished by unfettered ideal personalities, it has this unquestionable merit that it provides against the perils of the incalculable vicissitudes of personal will and strength. It is probably along these lines

that Abbe was guided to the step which he took. In support of this view we may quote the introductory words of the circular by which he announced to the members of the staff the transference of his sole rights in the Carl Zeiss Works and his share rights in the Glass Works to the Foundation as the new impersonal owner. The circular in question opened with the following words: "In order to provide now and in the distant future for the economic security and appropriate administration of the two undertakings more effectively than is within the powers of private owners and in order to prepare during my lifetime suitable provisions to this end, I have . . . ."

The perusal of the charter of the Foundation, while it affords a great intellectual enjoyment, bears evidence on almost every page of the years of reflection, of inward struggles, and of weighty decisions of which it is the ultimate fruit. The critical reader of this historic document feels that its author entertained no delusions as to this or that provision being far from perfect, if not an actual evil, though the smallest of several alternatives. Many must have been the times when it occured to its author that this or that provision needed a different form, but in every case and at all times his clear grasp of the whole led him to subordinate particulars to fundamentals. Though he did not lack the counsel of friends near and dear to him, there is no question that the whole charter is in every essence his own work. As a legal achievement, if nothing else, it was such that the faculty of law of a university conferred upon Abbe the honorary degree of a doctor of law. The magnitude of this achievement lay equally in the originality of the problem and in the succinctness of its solution, and its very imperfections were of that order which it necessarily shared with all laws and indeed with all measures which restrict the freedom of personal and instant decision of action. It is probable that cases may arise where the directing powers for the time being may view one or the other provision as an impediment, purely from the point of view of the interest of the whole, and it may happen that these impediments may arouse feelings of condemnation. It is precisely then that these provisions may avert fatal consequences. For, bound to act in the spirit of the founder, these same directing powers will irresistibly be led back to the motives which impelled the founder to set up these very provisions as an imperative safeguard against any swerving from the fundamental spirit of the whole [1].

[1] It is to be regretted that it should be necessary to utter a strong protest against opinions and rumours which ever since the establishment of the Foundation have been persistently revived, though they are palpably the product of a fatuous and malicious spirit. In the eyes of certain persons unable or unwilling to perceive the truth of things

It goes without saying that the provisions of the charter were not left impenetrable to the correcting influences of practical experience. It provides for this contingency in the following manner: Up to the end of the tenth year of the charter coming into operation, that is to say, up to 1906, modifications as well as supplementary and informatory additions and, if necessary, the reframing of entire paragraphs were left to the joint discretion of the executive of the Foundation and the founder himself. Changes instituted in this way after ratification by the sovereign authority forthwith became operative. But after the expiration of the first ten years these preliminary conditions underwent a complete change. Modifications then became admissible only in the event of the premises upon which rests the whole of the arguments embodied in the charter either coming in conflict with changes in their legal consequences or in the existing technical and economic conditions to such an extent as to render it impossible to fulfil the purpose of the Foundation while acting in strict accordance with the provisions of the charter, or introducing if upheld, consequences which in the near future could not fail to render these provisions impracticable or even palpably opposed to the clearly implied intentions of the founder. Any proposed changes coming within this category, are required to be submitted to a clearly indicated group of parties concerned, comprising the trustee, the works committees, associated owners, the employees, descendants of the founder, the University, and the affected district councils,

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Abbe has appeared as one who has perpetrated a wrong against his family (wife and two daughters) when he surrendered his ownership to the Foundation, and some go so far as to suggest that the family were enduring privation and that the charter should be looked upon as invalid since the donor's action proved that he had ceased to be in full possession of his faculties.

The actual facts of the case, briefly put, are these: (1) It goes without saying that Abbe's family has received the legally prescribed share, and its surviving members live in precisely those circumstances which accord with their wishes and needs (Mrs. Abbe died in 1914 after a prolonged illness). (2) The terms of the charter were approved by the government of the state of which Abbe was a subject and it was confirmed by the reigning grand-duke, while the faculty of law conferred the honorary degree of a doctor of law on its author. (3) At the time when the charter was framed Abbe was not only perfectly sound in mind but also endowed with an astounding freshness, clarity, and vigor of vision. (4) His subsequent illness was not a mental disorder but the purely physical consequence of an excessive use of soporifics, while the insomnia with which he was afflicted was the regrettable but perfectly intelligible penalty which he paid for his prodigious mental achievements in the wide range of science, technique, and practical sociology in which he engaged. (5) All these arguments will necessarily remain unintelligible to those who are only able to view all actions and all humanity in terms of their narrowly circumscribed bourgeois natures.

and they do not come into force until a year has passed and after objections, if any, have been heard in a court of law. This procedure and more particularly the first four paragraphs of the charter relating to the aims, the name, the seat, and the organs of the Foundation may not undergo any changes, neither is it permitted under any circumstances to except individuals or groups of individuals from the effects of any change in the provisions of the charter or to indemnify them against any such changes.

After having been in tentative operation, the charter of the Carl Zeiss Foundation was officially approved by the then ruling grand-duke of Saxony, and on the 1st October, 1896 entered upon the stage of full legal force. The revision provided for at the outset took place in 1905 and led to several changes of no small importance. This revised charter has been in force since the 1st January, 1906 [1]. Guided by its provisions, we now propose to review the social institutions of the undertaking as well as such incidental matters as are not directly affected by the provisions of the charter.

Before doing so we will assist our vision by considering a few general aspects bearing upon the whole.

It is usual to ascribe to those who institute large benefactions the attributes of magnanimity, and it is accordingly usual to speak of the large-heartedness which moved Abbe when he created the Carl Zeiss Foundation. In the very sight of his magnificent deed it is inevitable that it should be identified with the promptings of a lofty spirit, and it is quite certain that such shining examples of human nobility will be rare indeed. So soon, however, as we attempt to identify our outlook with the spirit which impelled Abbe we feel far from sure that the dictates of a large heart cover the *whole* ground. It is quite certain that Abbe was not moved, as charitable persons mostly are, by a desire to do an act of benevolence, however high he may rank as a benefactor. From the height of his ethical outlook he regarded what he was about to do as a solemn and unshirkable duty towards his undertaking, those employed therein, and everything in and about it. The fact that he was urged by this sense of duty does surely not detract from the greatness of his deed, while the spirit within him which saw a plain duty in a meritorious act places him high above all those benefactors whose sole merit lies in the deed as such and no further.

To whom does a factory belong?—Many are the answers to this question, and two of them represent the possible extremes either way.

[1] In the third volume of the collected papers of Abbe (Jena 1906) the charter will be found reprinted together with its variations, its underlying principles, and commentaries (pp. 262—402).

One extreme would regard as the moral owner the finder of the working capital, the other the active workers. The former is the fundamental aspect which at present rules almost universally, while the latter idea has been realised only in a few and not always happy cases. Both ideas are one-sided in similar degrees. Justice should compel us to include in the partnership all those who are active in the creation, maintenance, and expansion of an undertaking, as well as those who have been actively engaged and those who will be so engaged in the continuance of the establishment. Of these three sets of human beings the living are most easily to be satisfied. Salaries, wages, profit sharing, insurance against illness and old age, and so forth provide the requisite means, as we shall have occasion to consider in detail. But how are we to do justice to the dead and those yet to come? True, the dead have received their reward in their time, but this reward was only for what they were able to do for the undertaking during the active portion of their life time and for the achievements which endure after their death, not for the foundations which they have implanted for the further development of the undertaking, not for the sum of experiences which they have contributed for the benefit of the succeeding generations. And as for the future generations—well, let us hope that they will not be deprived of their just reward! Hope is a good thing, but is it not better to anticipate the future, if not wholly, at least partly? If we admit the reasonableness of these aspects there only remains the question as to how they are to be embodied in practice and who are to be entrusted with the claims of the departed and those to come. A little reflection will tell us that there is only one party which is truly and legitimately qualified to discharge this trust, and that is the undertaking itself, not those who happen to be engaged in it at the time being, but the undertaking as such and regarded as its true and only owner.

And then comes this other question? Who are the workers who have contributed to the creation and expansion of the values embodied in the undertaking? One instinctively turns to the employed persons of the past, present, and future. But apart from these there are two impersonal contributors who cannot be overlooked. These in the case of the Zeiss Works are science, under whose maternal wings it was nurtured into greatness, and the soil on which it has grown and the atmosphere in which it has breathed. For this reason the University, on the one hand, and the town and population of Jena, on the other, were to be considered as justly entitled participants.

There is, however, one personality which appears to have been "inadvertently" overlooked. That personality was the giver of the capital.

Viewed from the angle of the régime which since the middle ages has ruled the economic life of Europe through the instrument of interest bearing capital there can be no doubt that those who have provided money for establishing an undertaking constitute the essential agents without whom it could neither have been called into life nor developed. In complete keeping with this ruling principle Abbe dissolved his relation to his associate in ownership, but when thereby he had become the sole responsible owner he accepted the full consequences of his aspect, which did not recognise the established right to the exaction of interest on capital. True to this aspect, he renounced his personal claim to ownership and invested the undertaking itself, which was already performing all other functions, with the administration of the capital.

As a matter of fact, it is not formally correct to identify the present owner with the undertaking itself, for this, if no other, reason that apart from the optical works the glass works as well as other organisations enter into the scheme. The owner, properly speaking, is the *Carl Zeiss Foundation.* Its sphere of ownership embraces, apart from certain participations in other enterprises, the Optical Works and the Glass Works, the latter until April 1919 in conjunction with Dr. Schott and subsequently as Foundation property pure and simple, Dr. Schott having transferred his share to the Foundation and having exchanged his position as an owner for that of a member of the directing staff.

Before concluding this section we will not omit to point out the incorrectness of a frequently expressed view. It has been said that the Carl Zeiss Foundation and its undertakings are nothing more nor less than a cooperative association. In half a sense this is quite true. It is correct inasmuch as no capital is introduced from outside, instead of which the enterprise generates or augments its own capital and inasmuch also as in this case capital is not, as ordinarily, the master but the servant of the work. It is, however, incorrect inasmuch as the course of the undertaking is not conducted by the associated workers but by a permanent authoritative body and inasmuch as this body is not responsible to the individual constituent members but to the whole only. However, the members do not in any way cooperate financially but solely with their ability to work. Briefly stated, and to use Abbe's own definition—*The optical establishment is a cooperative association for production, but solely within the limits of its economic interests and not in regard to administration and management.*

Hence the Foundation embodies only the good, to the exclusion of the dangerous, side of the cooperative system. This is a great good fortune for all concerned, including those who experienced difficulty in realising the blessings of this limitation.

General Standards affecting the Active Life of the Foundation.

With the majority of foundations the conditions are very simple inasmuch as there are only two mutually related quantities, these being the endowment and the purposes which it is to serve. The nature of the capital, the manner in which it bears interest and so forth have nothing to do with the application. In the case of the Carl Zeiss Foundation things are fundamentally different. Here a favourable soil for the application of work on the part of a large number of people constitutes both *the means and the object of the foundation, and the beneficiaries of the foundation are also its maintainers and augmenters.* Employees and operatives of the works, the community, and the university all participate in the creation of values, and these are also the elements which are to gather the fruit. A narrowly defined interpretation between means and purpose naturally demands special provisions, and the great art of formulating them consisted in avoiding excessively narrow limits no less than excessive breadth.

Let us now cast a glance upon the general standards which govern the business life of the Foundation.

The industrial scope of the establishment is required to move within a definitely circumscribed boundary, at the centre of which naturally stands the science of optics, the technology of glass, fine mechanical and scientific instrument making. These may be associated with any of the necessary auxiliary branches of manufacture and any of the "related industries". Abbe wisely framed the limitations in these general terms so as to leave the door open to future expansion. The answer to the question as to what is a related industry is one which is subject to continual shifting, and for this reason the charter provides the requisite latitude for a free movement with the times. Viewed in its ultimate consequences this limiting provision signifies nothing more nor less than that the industries embarked upon should always be of a kind which can be regarded as maintaining a connecting link between science and technology, be it in the matter of the manufacture or the practical application of the products. The Foundation is not permitted to venture with its resources into domains of industry which lie outside this broad boundary. It may not even do so in the shape of invested surplus capital.

Beyond these fundamental restrictions no obstacles stand in the way of a sound spirit of enterprise seeking to extend the resources of the Foundation. Hence it is permitted to take up fresh lines of manufacture, to establish new branches and agencies and to erect new branch works.

But such added establishments, like the parent establishments, may not be disposed of, so that when the continuation of such an establishment should cease to serve its original purpose it is required to be dissolved. There is no restriction as regards the seat of new workings at home or abroad, but none of the parent establishments may at any time be removed from Jena or its immediate vicinity.

The business aims of the organisation differs radically from that of manufacturing and trading businesses as usually conceived. It is not here a matter of securing the highest rate of net profit but rather of bringing about an increase of the total yield above outgoings. In this we recognise a natural consequence of the linkage of the means and the purpose; for wages, elsewhere a burden, under this system become one of the essential aims of the yield. They figure accordingly in the balance sheet not on the loss side but on the profit side of the profit and loss account.

In conclusion there is an ideal side to the spirit of production ruling at the Zeiss Works. The establishments of the Foundation are not intended to confine themselves to remunerative production; they are at all times to keep in view the general progress of the technical arts and branches of science with which they are concerned. It is their mission to pursue also as far as practicable problems which do not promise any immediate material advantages.

The Administration of the Foundation and the Directorates of its Undertakings.

An intellectual effort is needed to correctly visualise matters relating to the administration and works management of the establishments concerned in that, on the one hand, the Foundation and manufacturing establishments are two rigidly distinct entities, whilst, on the other hand, they are linked up by an identity of persons. In actual practice this naturally presents a much simpler aspect.

The representation of the Foundation, the administration of its assets, and the supreme direction of its affairs lies in the hands of a board of administrators. One whould naturally wish to know who were the persons selected to discharge this responsibility. Obviously it could not have been individual persons, for if the principle of a charter stood for anything, this would only have proved a leap from the frying pan into the fire. Rather was it imperative to find a person in the abstract, whose functions might

survive the vicissitudes of individual life and therefore could be relied upon to endure for all times. After mature consideration it was found that none but the government of the country was likely to satisfy this requirement, and in view of the scientific character of the undertaking and its relations to the university the choice very naturally fell upon the education department of the grand-dukedom of Saxony. It is, however, to be observed that the controlling force of this official form of administration is indirect rather than direct, and this brings us face to face with an erronious conception which in the earlier stages of the scheme prevailed in wide circles. It must be clearly understood that the undertaking is not subject to the control of the government administrator but solely to the provisions of the charter, while it is the sole function of the official administrator to preside over the faithful and logical interpretation and application of these provisions. This aspect alone forbids any attempt to describe the undertaking as being now under "state supervision". Moreover, the provisions expressly state that the education department may not in its administration of the affairs of the Carl Zeiss Foundation observe the interests of the state to a greater extent than is the legal duty of any private individual. In practice this may be a figment, for a ministry of state which also happens to be an administrator will most certainly pay exacting, if not indeed preferential, attention to the interests of the state, especially where revenues are concerned which are payable to state institutions. This consequence is not weakened by a provision whereby the administrator of the Foundation is represented by a special trust commissary, who is required to be a state official but who performs his functions in relation to the Foundation in an *unofficial* capacity, receiving a fixed emolument from the Foundation, and who is solely guided in his actions by the charter.

Apart from the existence of an administrator and a commissary, a characteristic feature of the Foundation is furnished by its representation in all matters concerning the undertakings coming under its provisions, there being for each undertaking a director with full powers and his deputy. These appointments establish the unity referred to in that the persons holding them belong both to the Foundation and to the works management. This system has the merit of being calculated to strangle in the bud any possible conflicts between the two factors.

The works directorate (i. e. the business management) appointed by the administrators consist of two to four members so constituted that at least one directing member of the Optical Works should also belong to the directorate of the Glass Works. It is particularly to be noted that the members of the directorate are selected from the working staff of the factory,

and in so far as the discharge of their duties as managers and administrators does not engage their whole attention they continue to pursue their special avocations as they did before their appointment. Personally they do not cease to be colleagues of all the other members of the working staff, and it is only *in the collective* that a position of authority is vested in the directorate.

At the time when the charter came into force the directorate of the Zeiss Works consisted of Prof. ABBE, Dr. CZAPSKI, and Mr. MAX FISCHER (the latter as commercial director) and Dr. SCHOTT. On April 1st, 1903 Prof. Abbe retired from the directorate in view of his vacillating state of health and also in order that he might be able, after sufficient recovery, to resume his scientific work, which had been completely interrupted by his organising work. The strength of the board was restored by the accession of Prof. STRAUBEL. Soon after, Dr. Schott withdrew from the directorate of the Optical Works in order to be able to devote his undivided energies to the Glass Works. After the death of Prof. Czapski on the June 29th, 1907 Dr. Schott rejoined the board temporarily until 1908, when Dr. eng. BAUERSFELD became a member of the board. In view of the largely increased volume of business a fourth member has joined the board in the person of Mr. KOTTHAUS, who is an engineer by profession. In the Glass Works the directing board is composed of Dr. Otto Schott, Mr. RUDOLF KLETT as commercial principal and Mr. HIRSCH (engineer). The state commissary's office has likewise experienced repeated changes in the personnel. Privy Councillor Rothe, who became leading minister of the grand-dukedom (being the last to fill this office) was succeeded by Privy Councillor VOLLERT of the Education Department, who in his turn was succeeded by Privy Councillor EBSEN (now President of the High Court of Commerce). The principals (in a legal sense), finally, with full powers for both undertakings were formerly Prof. Czapski with Mr. Max Fischer as his deputy, while since 1907 Dr. Max Fischer occupies the position of principal with Prof. Straubel as his deputy.

All *matters relating to the personnel,* in view of the significance which attaches to these from the nature and purpose of the Zeiss Works, are dealt with in a special department established at the beginning of the century and since July of 1906 presided over by Dr. SCHOMERUS.

Just as at the time of its inception the Foundation was associated with an individual partner, there is nothing in the way of similar relations being entered into in the future. As a matter of fact, such another case has occurred, though in the mean time the relation has become merged in the general scheme of impersonal ownership.

The Economic Position of the Staff and Factory Workers.

For the proper understanding of the economic condition of all employed at the Jena Works[1] as well as the primary aspects which have guided the founder in this respect we must look as far back as the beginning of the strife between craftsmanship and the industrial system, which fills the pages of the world's history since the middle of the last century. At that time, at least in Germany, craftsmanship still ruled almost without opposition. In our days organised factory system as distinguished from individual and independent workmanship, predominates to a large extent, and the tendency is all in this direction. The state and individual err seriously if in all their social movements they fail to take into consideration the ways and means by which the advantages of the modern economic order may be taken full advantage of and at the same time its disadvantages rendered as little harmful and the harshness of its operations smoothed down as much as possible. The goal which is to be pursued is clear enough to every one. What is needed is to raise the modern successor of the craftsman, who now performs the economic work of the nations, to an economic level and legally definable position which may enable him, despite his loss of his economic individuality, to grow on the soil of the vanishing handicraft a sound and healthy life of the people. What is required in order to achieve this is to develop the existing regulations affecting the conduct of labour and the laws promulgated for the protection of life and limb until they ripen into an enforceable right of the workers and employers.

This program, it will be perceived, is diametrically opposed to the "patriarchal" system, which would be content to simply transfer the conditions of mediaeval handicraft to the system of modern industry. The social order adopted at Jena has nothing to do with this latter aspect. It regards the employed worker as absolutely free to think, to act, and to refuse as he wills, with the two sole exceptions that he should obey the laws of the country (which are in the hands of the state) and that he should fulfil his duties as a worker (which devolves upon the business management to insist on). All obligations arising out of the employment relate solely to the performance of the contractually defined work which he performs. The directorate has no further authority over him and may not impose any

[1] An authentic account of the socio-political institutions of the Zeiss Works may be found in a booklet written by Schomerus and entitled "Das Arbeitsverhältnis im Jenaer Zeisswerk", 7th edition, 1919, publ. by B. Vopelius, Jena. This booklet may be obtained from the works free on application.

restrictions, directly or indirectly, in the conduct of his life (Apprentices naturally constitute an exception, in that their freedom is restricted as that of individuals under tutelage). On the other hand, the scope of the workers' duties must not be taken in an unduly narrow sense. It goes without saying that it embraces all that appertains to his service, including all that relates to the secure, orderly, and careful conduct of both administration and production, the relation of individuals and their superiors, proper authority within the service, in short a reasonable observance of all factors which go to maintain successful working.

To instance particulars, it is interesting to note that any employee is entitled to accept an honorary office in the service of the empire, the state in a narrower sense, or the community and to obtain leave of absence (without loss of salary or wages). No questions are asked respecting his religious or political principles or his connection with social, economic, or political associations.

The right of coalition and the *formation of committees of factory workers and other employees* were admitted and secured at an early stage of the history of the Zeiss Works. The constitution and activities of these committees provided an important preparation for the law and regulations affecting shop stewards and workmen's councils. The *Zeiss Works Council* with its committees of workers and office employees and their subcommittees (dealing respectively with organisation, dismissal, wages, etc.) have become an effective means of cooperation in the general conduct of the affairs of the works.

This may suffice so far as the *legal rights* of the person are concerned. In the matter of the *economic rights* we have to make a distinction between the staff employees, time workers, and piece workers. The members of the office staff include the foremen as well as the scientific, technical, and commercial employees and receive fixed salaries. The operatives are either waged on the piece work principle or, where it is not practicable to fix a scale on the piece work basis, they receive time rate wages. It is, however, important to note that for the piece workers there is a minimum wage standard on the time rate basis [1]. Midway between the operatives and the

[1] At an early period, in fact soon after his association with the firm as a partner Abbe recognised the significance of the piece work system in the manufacture of scientific instruments and he even introduced piece work in the face of strenuous resistance on the part of Carl Zeiss and the workers themselves. The result furnished a brilliant confirmation of his fine judgement. Despite the tentative caution with which the piece work rates were fixed in anticipation of an increased output, the operatives were able to nearly double their wages.

scientific, technical, and commercial staff there is a category of deputy foremen, charge-hands and office assistants, who form a grade above the operatives under special agreements.

A peculiar interest attaches to a well considered provision laid down by the founder, by reason of which no member of the staff of either establishment, those of the supreme directorate included, may receive a salary exceeding an amount equal to ten times the average annual wages of work-people above 24 years of age and of at least 3 years standing calculated at the time when the rates of salaries are being fixed. The intermediate salaries are subject to similar restrictions. The effect of this provision is that the scale progresses at a moderate pace in an upward direction and that it reaches a definite limit. It is only too well known that in other large concerns the leading persons are frequently paid much higher remunerations, which may even rise to veritably phantastic heights. It may therefore appear arguable as to whether such limitations as the founder introduced were justifiable. It may be contended that an undertaking such as the Zeiss Works, which stands at the very head of an industry and intends to maintain that position, should consider it its duty to always fill the leading positions with persons capable of the highest achievements, even where the required degree of proficiency is only to be secured by making considerable material sacrifices. It is argued that such sacrifices are speedily recoverable. It is asked, why should an eminently proficient expert be denied the means of being, say, an art collector or ardent sportsman outside his profession? And human nature being what it is, it is argued that it is not practicable to cut off limbs without damage to the organism as a whole. In other words, if you cut off a man's pleasurable desires, are you not also liable to impair the pleasure he takes in his professional work? Such contentions are well worthy of consideration, and we may be sure that the author of this principle of limitation did not lend a deaf ear to the argument. What doubtless decided him was the widely existing disproportion between the exorbitant incomes of individual leaders in industries and the bulk of the employees and operatives, and he was further moved by the knowledge that this disproportion was far in excess of relative merit. Now, it was entirely foreign to the spirit of the Foundation to permit contrasts exceeding a reasonable and justifiable limit, and in the well considered opinion of the founder the limiting ratio of one to ten appeared to be ample.

The period of continual devaluation of money in Germany, which set in at the end of the war, has not failed to affect the system of waging obtaining at the Zeiss Works. Since no one could tell whether the devaluation would be permanent, what would be its extreme, and whether there would

be a return movement, the skeleton of the established system of waging was retained and the changing exigencies of the times were met by putting on a patch here and there, making shift with supplementary contributions in respect of the cost of living, and granting supplements per head and in respect of wife and children. It would take us needlessly far were we to enter into all the details of this development, especially since they have no fundamental significance. In April 1924 a conscious return was made to the pre-war principles of waging. The pension bearing wages were restored to a level of 85 per cent of the pre-war scale. The remunerations of the staff members and operatives were fixed on a basis of not less than 85 per cent of the level of 1914, while the wages of the labourers and women had 88 per cent for their lower limit, and pensions and compensations for discharge have been similarly adjusted.

Profit Sharing.

Persons who have heard accounts of the special organisation of the Zeiss Works at Jena are prone to declare that at the bottom of this organisation is the system of *profit sharing on the part of the work people*, while others have actually brought themselves to regard the establishment as belonging to the employees lock, stock and barrel. This aspect is wrong from practically every angle. In the first place, the profit sharing principle embraces all grades of persons employed in the establishment (with one exception, to which we shall refer later). In the second place profit sharing is not an essential part of the organisation, in that it is not a primary but merely a contingent link in the chain of provisions; and, finally, though it follows as a consequence of a strict application of the reasoning of the charter and its author, profit sharing can only be spoken of from an aspect which differs radically from that of the half-informed people referred to.

This is not the place to enter into a general discussion of the problem of profit sharing. A brief reference to an address given by Prof. Abbe before the Society of Political Science of Jena may, however, help us to view the cardinal aspects of the question. We may distinguish three forms of profit sharing: *First,* that form which is intended to pave the way for the formation of a cooperative undertaking. The attitude to the profit sharing system is then determined by one's attitude to the question of cooperative undertakings, where the whole of the workers represent the principals of the undertaking. Experience tends to show that the vitality of organisations of this kind is limited to cases where many may cooperate without a refined organisation, without a far-reaching articulation in their functions, and

without complication by the association of unrelated elements. The *second* mode of profit sharing is one instituted with the object of dealing economically with time and working resources for the purpose of enhancing the proportional gain on the output, in which the worker participates. In this case a kind of premium provides the incentive, but the effect is very imperfect and, pushed to its logical consequences, it is only an obscured variant of the piece-work system. The *third* species of profit sharing is the one which, amongst others, has been recommended by Freese as one of the most effective means for the elevation of the economic position of the work people and the most effective means of establishing goodwill between wage earners and employers. There is a very beautiful sound about this, but, when viewed in such a light as Abbe would bring to bear upon it, the illusion vanishes at once. One has only to remember that under the conditions of the present governing system wages are simply determined by the forces of supply and demand and, it will be realised at once, it does not follow at all that shared profit is necessarily an addition to the ordinary wage. On the contrary, it tends to depress the wage scale pan, for in consequence of the system the amount made up of wage and profit shared will be governed by supply and demand, and hence the worker has exchanged an uncertain thing for something which was at least certain for the time being. In relation to the employer the institution has the advantage of bearing the halo of a noble endeavour towards social betterment, because it creates the impression that the employer is voluntarily relinquishing something that he has the power to make his own if he so willed.

From this it will be seen that Abbe did not take a very friendly view of the principle of profit sharing, and yet he has included it in his charter. But here it figures merely as something admissible and not as an essential and necessary provision, though immediately after the charter had been put in operation the profit sharing system took likewise effect. How is this seeming inconsistency to be accounted for? What is it that brought Abbe to this change of front? The answer arises out of what we have said about the economic order which now rules or, we had better say, out of the labour laws now in force. These do not concern themselves with questions of wages, but naturally they do not prevent principles affecting the wage question being laid down in the provisions of private articles of employment, and this is what has actually been done in the charter of the Carl Zeiss Foundation. The pension bearing time rate of wage which any one in the employ of the Zeiss Works has attained and received for a year cannot be reduced in consequence of business being bad, and even indirectly this cannot be done by the usual process of discharge, as the provisions of the

charter render this a more or less costly procedure, since no one may be normally discharged without an appropriately graded compensation (see below). Since now in good times wages tend to rise it will be seen that under this system the wage movement becomes comparable to a ratchet wheel which may be turned in a forward direction only, but which cannot be reversed. When once it has been turned too far, or, indeed, turned forward in obedience to temporary conditions at a time when it should have been left untouched, it will not be practicable to remedy the error which has been committed, and this may operate to the serious financial detriment of the undertaking. It follows from this that the pension bearing wages should be rendered reasonably independent of the general profit earning capacity of the business. They cannot practically conform to the rise and fall in the state of the market, but all that can be allowed is that they may move upwards along the mean line of fluctuations. To use the words of Abbe, the large ratchet wheel is to be retained but the mechanism should have inserted in it a free-wheel which is capable of being turned backwards and forwards.

As a theoretical consequence it follows thus from the principles laid down in the charter of the Carl Zeiss Foundation that the remunerations arising out of the work (wages as well as salaries) are made up of three parts:

1) a fixed irreducible and pensionable portion,
2) a supplementary wage or salary scaled according to personal merit (excess earnings in piece-work, extra wage rate for time work),
3) a variable bonus portion governed by the annual proceeds.

If now we cast a retrospective survey over the question as a whole, we arrive at a significant result respecting the fundamental difference between factory organisations working under the traditional conditions and those obtaining within the Zeiss Foundation: This difference does not consist in profit sharing entering into the scheme of one undertaking and not into that of the other. The true difference, apart from its outer form, lies in the fact that the traditional profit sharing scheme is a disguised form of participation in profits and losses, while in Abbe's system participation is restricted to profits.

Moreover, it is to be observed that the term "profit sharing" has been purposely avoided in the final wording of the charter. It has been replaced by a term which, while less programmatic, adequately expresses what is implied, viz. "salary and wage supplement". With one exception, which will be explained later, it benefits all engaged in the work of the establishment in like measure in that it is supplied in the form of a certain percentage of the salaries or wages earned in the cource of the completed

year by the staff or factory worker. The magnitude of this percentage, which is the same for all, is determined by the amount of the resulting nett profit and the index figure of the cost of living during the year in question.

Here, then, we have a mode of distributing the first rewards of labour which is theoretically in apple-pie order. In practice we encounter that peculiar thing known as the human soul which is not always able to see eye to eye with the best of principles. Here, as elsewhere, much educational effort is needed to overcome unfriendly personal feelings and to render the participants ripe for a full understanding of the underlying principle. It should not be overlooked that the standard human mind senses in the most diverse spheres, both physical and spiritual, not so much quantities in themselves as their variations in the flow of time. Hence it comes about that a worker who receives a dividend of 5 per cent following upon a preceding one of 10 per cent experiences such a decline in the sense of a loss, and, he may consider himself as badly treated, though naturally without any justification, if in any year there should be no dividend at all. The Zeiss establishment has not gone through life without this experience. During the period from 1896 to 1902 the supplementary dividend or bonus, as we might say, had always varied within the limits of 5 to 10 per cent and had been 9 per cent on an average, that is, the bonus had been the equivalent of about one month's salary or wage. When it became known that for the year 1903 no bonus would be forthcoming a spirit of discontent found expression among a large number of the employees, which clearly indicated that the complainants considered themselves defrauded of something that was justly their due. Many had come to rely on the bonus and had included it in their calculations. One declared himself compelled to give christmas the go-by, another complained even that he would be unable to meet his debts, as if the normal pay obtaining at the Zeiss Works were not more than adequate in itself to meet all normal contingencies. It seemed to have been entirely forgotten that the bonus can reasonably only be regarded as a provision to meet extraordinary cases. Nevertheless, the advances applied for were so extensive that they became a troublesome burden to the management. A cooperative credit supply association was accordingly established, and, as a matter of fact, this scheme has worked satisfactorily. Surveying the situation with the detachment of an onlooker interested only in the study of social economy, one cannot but view as a blessing in disguise the occurrence of a year in which the available bonus reduced to zero. Obviously the longer such an occurrence had been deferred the more serious would have been the effects of its sudden explosion upon minds which had come to regard it as a thing always to be reckoned with.

Since 1904 every year, with the exception of 1923, has produced a considerable bonus ranging from 4 to 10 per cent, as will be seen from the subjoined table:

1896	1897	1898	1899	1900	1901	1902	1903	1904
8	5	9	10	10	10	8	0	5
1905	1906	1907	1908	1909	1910	1911	1912	1913
9	10	10	8	8	8	8	9	9
1914	1915	1916	1917	1918	1919	1920	1921	1922
6	6	10	8	7	5	4	5	55[1]

It may, however, be asked what are the circumstances which cause the margin whence the bonus is derived to decline or fail altogether. The inspection of this question discloses such important and interesting relations that we will bestow a few words upon it.

One's natural impulse is to say, there is nothing in it. The obvious cause is the decline of profitable business. No doubt, this is the most obvious cause and in general it is probably the most frequent cause, but neither in the case which involved a drop from 8 to 5 per cent (1897) nor in the other in which there was a complete absence of surplus profits (1903), could bad trade be made accountable for the decline of profit. At the very least, it was not a significant factor, since the unceasing development of the Zeiss Works had so far completely spared the establishment the experiences of bad times. The true cause had to be looked for in the unreasonably high piece work rates. A careful analysis led to the discovery of the fact. What had led to such an analysis being instituted was the disappointment which the business management experienced when it found itself unable to distribute bonuses. The entire state of business had justified fair expectations, and an inquiry was instituted to discover the root cause of the deficiency. As a result of this inquiry it soon transpired that the piece work rate had been so high during the year that some of the piece workers had been unduly favoured at the expense of the other piece workers as well as of all the other employees. *The principle of profit sharing, apart from its immediate intention, was thus found to perform another function of the utmost importance to the business management. It proved to be a sensitive barometer for the purpose of properly gauging the piece work rates and other*

[1] This abnormal figure is due to the inflation then obtaining. The amount actually paid out corresponded to $2^1/_2$ to 3 weeks earnings.

overhead expenses, and it provided a danger signal calling for rectification where an error had occurred. There is, of course, another possible cause, viz. the rating of the depreciation, but this is a point we need not pursue.

The only persons who are excluded from participation in profits are the members of the managing directorate, that is those very persons who in an enterprise founded upon the traditional economic pattern, such as joint stock companies, are frequently the only recipients of percentages on results. The underlying motive for this provision, which at first sight cannot fail to strike a mere bystander as somewhat strange, becomes explicable when we consider that upon the managing directorate devolves the task of the preparation of profit and loss accounts and balance sheets with all details relating to salaries and wages, reserve funds, apportionment to the various cash accounts, selling prices of the works products, etc. From this it will be seen that the directorate has it in its power to force the nett profit up or down within certain limits, and as this determines the amount which would become available for profit sharing purposes, it might conceivably experience an inducement to adopt the former plan so as to be enabled to fix upon a high profit sharing figure which would benefit in full all receivers of salaries, including the managing directorate itself, whilst the waged workers would only receive the excess over the reduced wage rate, which in certain circumstances might in the end produce a negative result. In the face of the logical rigor of this provision it would seem pardonable to contend that the principle of the ethical optimism upon which the entire organisation is based breaks down in the case of the members of the managing directorate. Indeed, the very logic of the provision might be met with the contention that the charter itself contains guarantees for drawing up profit and loss accounts which are unaffected by contingencies such as we have sketched above. All said and down, the exception is significant only as a formal expression of a principle, for actually the addition of a share of profit to the salaries of the members of the directorate would still leave untouched the main fact that these salaries are low as compared with the corresponding salaries paid under the traditional system.

On the other hand, the members of the directorate are not excluded from recognition of special services, for which the charter provides. This provision relates to achievements placed at the service of the Foundation by members of the staff and by factory employees possessing special merits, such as inventions or contributions of technical or economic value to the establishment. Incidentally this provision would seem to be a concession made to the prevalent conception of reward due for special individual

achievements. A man, who like Abbe, placed his intellect in its entirety at the service of the establishment would rightly expect the same from all operating with him, and, strictly speaking, there lurks an illogism in a convention which says: You shall do for the undertaking the very utmost of which you are capable, but if you do more you shall be rewarded. However, in practical life logic is one thing and psychology another, and the latter proclaims that it is only right and fair that he who adds an extraordinary advantage to the resources of the establishment which he serves should be given a share in such advantages. Actually, this provision has been freely put into practice, and this will be continued in future. It is one of those incidental phases in the practical workings of Abbe's charter which dispose of such myths as the "Spartan régime" of the Carl Zeiss Foundation. The provision embraces both far-reaching inventions of leading staff members (one of whom, to instance a case, has received thousands of pounds sterling for the epoch-making photographic type of lenses invented by him) and small devices and suggestions which have emanated from foremen or operatives, for effecting improvements in construction, in the workshop or elsewhere. In relation to the higher grades of the staff this measure provides a compromise in the face of the limitation imposed upon their remuneration, which in the case of the directing members offers a potential compensation for their exclusion from the profit sharing system.

The Working Day.

The number of working hours in the day, as we well know, has been one of the most intensely controversial questions of fundamental significance in the social problem, and it has not failed to provoke fierce economic battles. The mere conception of a working day of ten hours for female factory workers had to force its way through a heavy barrage of economic and political resistance. In 1918 the eight-hours day became law in Germany under the republican régime, and is now also forcing its way into the economic life of other countries. Strife now merely centres around certain interpretations and details, such as the question of preparedness to work (as distinguished from work itself), the admissibility and scale of payment for overtime, the question as to whether in certain phases it is economically expedient and necessary to shorten the working day to eight hours. It would appear that for the present the eight-hours working day has established itself as best suited to meet industrial needs, and those employers who still question its wisdom will do well to adapt themselves to its rule. But as public opinion will continue to occupy itself with the discussion of

the theme it may be interesting and useful to review at some little length the train of thought which induced Abbe already in 1900 to introduce the eight-hour day. There is all the more reason for hoping that this may be done with profit since Abbe's reasoning, which has been tested in the school of practical experience, has been described by Schmoller as the best contribution which has yet been made to the problem of the industrial working day.

Social battles, like other battles, are fought out between two parties. The question regarding the identity of these contending parties can be answered in three different ways. The first, most obvious and also most trivial, answer points a finger to the employer and the employed. The second views the phenomenon as a battle of the employer joined by the reasonable workers, who realise that they share common interests with their employers, against the unreasonable workers. The third aspect, which is fundamental in the whole of Abbe's social thinking, views the whole thing as a strife between all reasonable minds on both sides and all unreasonable minds on both sides. The significant feature of this aspect is that it obviously aims a blow at the fiction which recognises the existence of reasonable and unreasonable workpeople but which looks upon all employers as inevitably reasonable.

Now, it is precisely this quarrel set between two parties which provides an excellent schoolbook example for testing this mode of classification. The backers of the first aspect believe that it is obviously in the interest of the employer to extend the length of the working day as far as possible, whilst the workman desires the shortest day possible, assuming, of course, that there is a fixed day wage. The employers of the second group, the patriarchs, say to their workers: We will make you a concession, but you must not be unreasonable and ask us to sacrifice too much. Both aspects proceed on the tacit assumption that what is an advantage to one party is necessarily adverse to the other. Now, this assumption is, in truth, begging the question with a vengeance, and Abbe proceeded to put it to the test and in so doing discovered that there was no truth in it. He found indeed by actual experiment and subsequent experience that excessively short hours are prejudicial to the undertaking, while excessively long hours injure the worker. Between the two extremes there is to be found a golden mean which is equally advantageous to both contracting parties. The main problem is to scientifically establish this mean in order that it may serve as a basis for organising a time table. It is scarcely to be expected that this golden mean will be the same for all branches of industry without distinction, it is also likely and even certain to assume different values

according to the locality. In a weaving mill it will be different from that suitable for an electrotechnical establishment; in a large city it will not be the same as it should be in the country. But there is no doubt that for every concrete case there is such a mean under which both sides fare best; —the workpeople because they conserve their life and health and secure the requisite interval to restore their vitality from day to day; the undertaking because it receives by this discreet use of the human machine ample and better work, besides economising its mechanical resources.

Though it may be true enough that excessive resting may result in the stiffening of the limbs, it is equally certain that judicious resting will enable exhausted forces to recuperate. No sensible employer should mobilise his forces without allowing a sufficiently long pause for recovery from preceding fatigues.

In a paper read in 1901 at two successive meetings of the Jena Association of Political Science Abbe discussed the problem of the *shortened industrial working day* in the light of his own experiences and in a remarkably clear and convincing manner. As far as the depth of his arguments admits of it we will endeavour to briefly outline their main issues.

At the beginning of 1900 the question *"Are you willing, and do you trust yourself, to accomplish in eight hours what hitherto you have achieved in nine hours?"* was put to the vote among the whole of the employees of the Zeiss Works. A majority of six out of every seven declared in favour of the experiment, and in deference of this expression of opinion the eight-hour day was given a year's trial. The results were satisfactory beyond expectation. In the case of 253 piece workers, where alone it was practicable for a variety of reasons to institute a strict comparison, the output as it obtained before the change was made was contrasted with that realised after its introduction. It was then found that the output had not only not fallen but had actually risen by four per cent; in other words, in order to maintain the previous rate of wage per day, the hour rate needed a rise of 12 per cent. Actually it had risen 16 per cent, and this result was found to hold for every age group and, with one uncertain exception only, also for every work department taken independently, the diversity of the involved processes notwithstanding. Obviously also the nett performance of the machines (after deduction of all unprofitable running) had very largely increased.

This *statistical* test was associated with a perhaps still more interesting investigation, which we may describe as a *psychological* test. This investigation was carried out without the knowledge of the workers and furnished particularly valuable evidence in that the result as such proved to be

contrary to what the participants in the test held it to be, so that there could be no question of the result being tainted with personal prejudice. It so happened that when the workpeople were provisionally asked to state their view of the effects of the eight-hour régime, they declared that they had made violent efforts in the earlier period of the new order to obviate a decline in their wages; however, they had not been able to maintain this standard for any length of time and had therefore returned to the old pace. They desired therefore a return to the previous nine-hour day as otherwise they would suffer a serious disadvantage. Now, the piece work sheets showed that in the very first days the output had indeed been abnormally high and that subsequently there had been a decline, but it was found that the condition to which they now had readjusted themselves was not, as they supposed, the old hour pace but rather the old day output and, as a matter of fact, even a little more. What had really happened is that very quickly they had lost the feel of that pace. From this it follows clearly that, whereas abnormal speeding up is productive of over-strain, a rate of speeding-up which is sufficient to maintain the day output, and which we may describe as normal acceleration, does not produce such an effect.

How are we to explain this remarkable phenomenon in its dual aspect irrespectively of and in relation to the personal element? It does hold good, as has notably been ascertained in England, for a wide range of different occupations, though the contrasted hours were not always eight and nine, as in the case of the Zeiss Works. The explanation must therefore rest on a general foundation which must be sought in the human element.

It is here where Abbe steps in to weave his statistical and psychological threads into a law which is as simple as it is ingenious. He expresses this law in the form of a mathematical equation, which states that, just as income and expenditure must be made to balance if financial bankruptcy is to be averted, so a worker must do the like with his physical and mental resources. If he continuously expends more strength than he is able to replace, let the difference be ever so small, the ultimate result of these continually accumulating unrepaired losses must lead to his undoing. Our equation assumes accordingly the form:

$$\text{Daily expenditure of force} = \text{Daily recuperation of force,}$$

$$E = R;$$

or, to put it in colloquial language:—Fatigue = Recuperation. *This is the conditional equation for the physiological balance of the industrial output of effort.* Expressed in its vague generality this statement supplies a very ordinary piece of wisdom. It attains, however, a wholly unsuspected

significance when it is realised that the two quantities E and R imply a strictly scientific meaning in the sense of physiological quantities and that both quantities may be reduced to their fundamental factors by an appropriate process of analysis. Fatigue is nothing more nor less than the consumption of substances which are indispensable to the organic system and the accumulation of other substances which are injurious to it and which in the long run act as poisons. The exact reverse takes place during the process called recuperation. In order that the reversal may be complete R should be equal to E.

The fatigue, that is the quantity E, is made up of three clearly definable components. The first part is solely determined by the amount of the daily *output of work;* the second depends upon the time rate at which the effort is put forth; the third part, which is the most important in reference to our problem, is the amount of fatigue which arises during the working pauses, during the snacks of rest, during the unproductive standing about or sitting within the noise, the restlessness and relatively bad air, etc. which pervades a factory. These many pauses of a duration of seconds and minutes are not useful in an additive sense, they do not, therefore constitute elements of repair, on the contrary they provide a further and wholly superfluous source of fatigue. This link in the fatigue chain of E cannot be better visualised than by likening it to the idle running of a machine without load, and one might indeed call it the *idle running of the worker.*

We shall now be able to appreciate the quantitive significance of our equation in its practical consequences. What is required is that the working hours should be gradually reduced so far as still to leave the two resulting gains made up of lengthened recuperation and the diminished idle running together greater than the damage done by an excessively increased time rate of work. The limit so found represents the *most favourable number of working hours.* This number naturally assumes different values according to the nature of the industrial occupation. It is governed by the difficulty and the strenuousness of the work, then again by the widely varying range within which it is at all possible for the working pace to move, since speeding-up is not solely a matter which rests with the worker but is also governed by the machines and other circumstances which are associated with his work. *The higher the character of the work and the greater the influence which the worker exercises upon the pace, the smaller also will be the most favourable number of hours to which the working day may be reduced.* The experiences gathered at the Zeiss Works, in other optical and electrical and engineering establishments have shown that in the case of a large proportion of industrial occupations the most favourable figure

has not yet been reached by the nine hour standard and that it is not sensibly exceeded by the eight-hour standard. The latter is therefore scientifically justified for these cases, in other words, that it has been shown that it best meets the interests of both parties,—the undertaking and those employed in it—, in both cases because the strength of the employees is maintained at its full height, for the undertaking itself, in addition, because the shortened day effects a saving in depreciation and working charges.

We cannot discuss this interesting problem in detail, but two points may be considered. It was found, as we have already mentioned, that in the case of the *piece workers* the output, instead of declining, actually increased. For the *time rate workers* the resulting effect of the shortened working day can only be arrived at indirectly from the machine output. This indirect analysis showed in this case also that there was no appreciable deterioration in the output. However, there can be no doubt that the output is not nearly so favourably affected in the time rate system of working as it is in the piece rate system, and this is only to be extected. It follows from this that the introduction of a shortened working day inevitably tends to extend the piece rate system as far as possible. In the eyes of those who look upon piece work as a species of sweated labour the beneficence of the eight-hour day may appear to be an illusion. Whatever truth there may be in this view, our investigation disproves the reasonableness of applying it to piece work in relation to the shortened working day. Piece work becomes murderous work only when an unnatural strain is put upon the human effort; it becomes a source of exhaustion to those who have no other thought but to turn out as much as possible. But we have already seen that this particular condition does not arise; on the contrary, that the worker adapts himself to the enhanced output required to make up for the curtailment of time; in fact, that he completely loses the sense of the increased pace. Whatever justification there may be for the condemnation of piece work is entirely removed by reducing the working hours to a scientifically balanced minimum.

This is one aspect. The other relates to the *extension of leisure* which results from the shortening of the working hours and especially to the question as to what the worker can and should do with this increased leisure. This question as a whole is no concern of the employer, but he can claim a special interest in so far as it bears on the whole principle and purpose of the shortened hour system, which would obviously be vitiated were the worker to continue during his leisure hours to perform any of those physical and mental functions which he applies during his vocational

occupation. The system, to be effective, implies that all such functions should be laid aside. At the Zeiss Works a provision to this effect is, in fact, in operation. Whether, however, an employee uses his leisure hours for doing nothing or whether he occupies himself with a variety of things is in the main immaterial to the administration as such. What a man chooses to do with his leisure hours so as to obtain the best measure of relief from the efforts by which he earns his living depends upon his taste and his physical and mental equipment as well as his domestic relations. To those who argue that increased leisure offers increased opportunities for abuse we can only say that whoever wants to loaf will not be prevented from doing so by having an hour or so the less at his disposal. But, in any case, to oppose any broadly conceived reform on the grounds that it may have unfavourable consequences for a few who wrongly enjoy its fruits is an attitude worthy only of cowards and casuists.

As a result of this preliminary trial the eight-hour working day was definitely adopted at the Zeiss Works at the expiration of the year on the first of April 1901. In the case of establishments of the nature of the Zeiss Works the system is undoubtedly of a great practical and ethical significance. We will not attempt to discuss the problem in relation to work of a simpler or easier kind or outdoor work (where frequently it is merely a matter of being on the spot, keeping an eye on things or animals, and being in readiness to act if required. There are also necessarily many cases where this superb idea, indiscriminately applied, could only result in a caricature.

When the eight hours day was universally adopted in Germany the Zeiss workers concluded that their position of advantage over other workers had ended; accordingly they reasoned that it was due to them to secure a further reduction of the working hours. In September 1919 a working day of 7 1/2 hours was agreed upon, and now it is interesting to observe the contrast to 1900. This time the body of workers did not trust themselves to perform in 7 1/2 hours what hitherto they had accomplished in eight hours, and hence they demanded at the same time an increased rate of wages. It was sought to justify this demand by arguing that the ravages of the war had been productive of such a state of malnutrition and physical deterioration that intensified working could not be suggested as a practical proposition. The business management agreed all the more freely to this demand as the principle of piece work, which had been dropped during the vicissitudes of the revolution, was once more put in operation at the same time that the 7 1/2 hour régime was introduced.

However, the forty-five hour week was not found to serve as a permanent working basis. At the end of 1923 the legal limitation of the working

hours to eight was relaxed and many industries returned to nine and even more hours. This was the appropriate moment for the Zeiss Works to return to a working week of forty-eight hours. Since the 9th February, 1924 the establishment works 8 1/2 hours a day, excepting on Saturdays, when it works 5 1/2 hours.

There are two more points which merit our brief consideration. One is the question of overtime. At the Zeiss Works overtime working is subject to voluntary arrangement, it is resorted to in urgent cases only, and is subject to a special high rate of remuneration. The other point affects the principle of a divided, as against a continuous, working day. The latter would have fitted more naturally into Abbe's system in that the divided day involves the necessity of resuming and interrupting work twice with consequent inevitable wastage. In his attitude to this question Abbe attached significance to the fact that Jena bears the character of a small town, and in deference to the normal life of small towns he decided in favour of a break of two hours for the midday meal. After the war the body of workers were successful in instituting a continuous working day. Later balloting has shown, however, that there is a growing preference for the older system, and, accordingly, in April 1924 a return was made to the divided working day. For reasons of uniformity the establishment prefers this arrangement since the office departments and a few other sections work on the bisected plan with a break about midday. It will be readily realised that elderly and ailing people had felt the continuous working system to be little short of a torment, and in the long run even the more robust found the strain to be excessive, especially towards the latter part of the day. In view of the intensive system of working adopted in modern industries the institution of such working pauses as will keep off fatigue as much as possible is of the utmost importance.

We will conclude this section with a short reflection, which at first sight may seem to bear no relation to our subject. Throughout a number of years it was customary at the Zeiss Works to cease work on the first of May at 11 a.m. When this became known a great hullabaloo arose in certain quarters and the thing was wildly denounced as a concession, nay a complete capitulation, to socialism. As a matter of fact, those only who had been present at the memorable gathering which heard Abbe's address on the eight-hour working day know anything of the true spirit and aspect of things. After developing with true scientific constraint, such as the subject demanded, the theory of the physiological balance of work and recuperation and deducing therefrom the existence of a most favourable minimum of working hours, Abbe supported his deductions with the aid of the numerical

data which he had gathered from his great practical test. In his peroration, which he delivered with rising warmth, he surveyed in moving terms what had already been achieved at Jena. He began by describing the appalling conditions as they existed about the middle of the nineteenth century, when a working day of thirteen to fifteen hours reduced a workman's life to a scarcely bearable existence. Then he proceeded to remind his hearers of the memorable bill which stands to the credit of the British Parliament of 1847 and which limited the working hours for women labour—that bill which called forth Macaulay's famous speech and which, once passed into law, set the stone rolling. That day on which the sun rose for the first time upon the social progress of the workers of the world was the first of May.

In later days the significance of this day changed unfortunately so completely that even such unprejudiced administrations as that of the Jena Works found themselves unable to retain the official May day as a day of remembrance. Unfortunately, a day of historical commemoration had become a day of political protest and assertion. The works continued therefore to run on the first of May, excepting that no worker who applied in good time was refused the leave which he desired on his own initiative. In 1922 the Thuringian diet instituted the 1st of May as a legal holiday, and according to the provisions of the charter of the Carl Zeiss Foundation full wages were paid on that day unless it happened to fall on a Sunday. A further loss in working days, which arose when the 9th of November was likewise adopted as an official holiday, was balanced by abolishing as a paid holiday the ecclesiastical day of repentance, which occurs soon after. The question of the festive days has been turned into a playball of the political parties. In Thuringia, owing to a change of political majority, the 1st of May has again been abolished as a national holiday, and hence the legal claim to wages was suspended on the 1st May, 1924, but leaves of absence were freely granted to applicants.

Special Welfare Institutions for the Employees.

In passing on to the special welfare institutions which the establishment has founded for the benefit of its factory workers and office staff to meet the exigencies arising out of the need of holidays, illness, invalidity, old age, and death we must look back far beyond the origin of the charter drawn up by Abbe. Provisions of this kind existed naturally long before Abbe modified and expanded them within the framing of the charter. On

the other hand, these institutions have not remained confined to the letter of the charter. In many respects they have been developed to meet contemporary needs.

a) *Leave of absence for time rate workers.* Commencing with the simple case of the annual holiday, which has become customary with a large section of the community, it may be asked, why in the name of fairness should the leave of absence with pay be granted as a matter of course to a clerk or other member of the office staff, yet be denied to a regularly employed and waged factory worker. The foundation charter provides for adult work people six days leave with pay at the standard rate of wage and six additional days without pay. After repeated expansions this provision as it now stands is as follows: After one year's service every workman is entitled in the course of the following year to six days with pay (apprentices without this interlude of one year). After the first two years the duration of the leave rises a day for every two years, reaching a total of twelve days in thirty years, after which it rises a day every five years to a maximum of eighteen days. The members of the office staff are entitled to twelve days leave, which rises to three weeks with the length of service. Since April 1924 the holiday pay to the factory workers amounts to the minimum time wage plus 30 per cent. This higher scale has been adopted in view of the higher cost of living during the holiday weeks, as established by experience.

b) *The Sickness Insurance Society.* In 1875 the optical works, which then counted sixty hands, established its own sick club, which was supported by the contributions of the members and occasional donations of the firm. In 1884 it adapted itself to the factory health insurance scheme which in the mean time had been established by legislation throughout the German Empire. Subsequently the works of Schott & Co. fell into line with the Zeiss Works. The sick pay for a period not exceeding six months amounted to three quarters of the members's weekly rate of wages, and in case of need the support could be continued for a further period of three months to the requisite extent. The member was free to choose his own doctor, and the contribution of the insured amounted to 1·2 per cent of the fixed standard wage, the firm contributing 0·6 per cent of the aggregate fixed wages bill. In 1892 the whole of the contributions to the sick fund was increased to 3·2 per cent of the fixed standard wage, and subsequently to 4 per cent of the daily wage up to the limit of 5 Marks. The excess receipts were employed to give the dependants of the workers the fullest advantage of the available benefits. The firm accepted on this occasion responsibility for half the average amount of all contributions without asserting its right of intervening in the administration of the fund beyond exercising its right

to veto proposed changes in the scale of contributions and in the provisions and in the event of the fund being dissolved. On the 1st January 1902 the time limit of the insurance benefit was extended to a whole year, while the sick pay amounted to three quarters of the insurable wage, and at the same time a sickness allowance fund was established which is maintained by the contributions of its members. This fund provides a means of bringing up the sick pay to the full amount of the wages which the member earns when in good health. Further measures for providing relief in sickness have been introduced in the course of the last few years, in consequence of which the rate of contributions has risen to 5 per cent. On the 1st January 1914, when the German national health act came into force a change arose in the administration of the sick funds inasmuch as a representative of the firm of Zeiss and Schott & Co. is required to occupy the chair on the council and executive committee and to exercise his legal vote. In October 1921 the institution established an excellently appointed *dental clinic.*

c) *Pensions Schemes.* Long before the state proceeded by legislation to deal with the question of compulsory invalidity insurance and old age pensions the Zeiss Works had instituted adequate provisions for the benefit of its work people. This scheme came into operation on the day of the death of Carl Zeiss in 1888 and went far beyond the limits of the legal requirements both in the matter of the amount of the pension and in view of the fact that the pensioners' widows and orphans participate in these pension benefits. The subsequent charter of the Carl Zeiss Foundation defines certain circumstances in which the benefits assume a still more favourable aspect. Such special conditions having actually arisen, the articles of pensions of the Carl Zeiss Foundation as they now stand are as follows:

Every staff member, office employee, assistant, and operative entering the service of any of the establishments of the Foundation before the completion of his fortieth year becomes entitled, after five years service, to a legal claim to a pension in respect of himself in the event of his becoming incapacitated or reaching the age limit and in respect of his widow and orphans in the event of his death. The five years service which confers a title to a pension counts from the completion of the eighteenth year as the minimum age. The maximum rates of the pensionable monthly income after five, ten, and fifteen years service are respectively 100, 120, and 140 marks for the workpeople. For the foremen, office employees and other assistants they are 120, 160, and 200 marks respectively. Of these basic rates the pension payable in the event of incapacitation amounts to 50 per cent in respect of service up to ten years, and subsequently 1 per cent in excess of 50 per cent in respect of every year beyond the ten years

service up to 80 per cent in respect of thirty years service. The old age pension becomes payable after the completion of the 65th year and after a service of not less than thirty years. A widow receives four tenths and each orphan two-tenths of the pension to which the husband or father would have been entitled in the event of his becoming incapacitated, but with this restriction that the total amount payable may not exceed 80 per cent. A widow without children receives five tenths of the pension which the husband would have received if incapacitated. During the period of inflation the pensions as computed on this basis were increased to meet the greatly heightened cost of living according to the scale which happened to be applicable to employees in work. In consequence of these conditions the pensions rose in both establishments as compared with the pre-war conditions at a rate proportional to the wages and salaries of the working employees, and now at the end of the inflation misery (since the 1st December 1924) they stand at 85 per cent. This must surely be acknowledged to be an achievement of no mean order, especially when it is taken into consideration that the devaluation of the currency naturally played havoc with the reserve funds of the Foundation, in so far as these consisted of trustee securities. It is in striking contrast to the pitiful collapse which the devaluation of the currency inflicted on the pension funds of private firms, life insurances and others. In conclusion it should be noted that in the event of death the survivors receive paid to them the amount of the breadwinner's wage or salary for a period of three months, and a pensioner receives for the first month double the amount to which he is entitled in order to assist him to effect the transition. No contributions are levied for the insurance of the employees and their dependants.

The entire pensions scheme has a very significant provision attached to it to the effect that an employee who has become entitled to a pension by reason of his incapacitation and who through illness or through any other circumstance involving no gross offence on his part has lost his ability to work can only be dismissed as a pensioner under the full terms of the scheme. This provision obviates any tendency to dismiss employees whom circumstances have rendered burdensome and thus to evade the onus of a subsequent pension.

d) *Compensation for Dismissal.* Amongst the demands set up by the labour parties of the world in their fight for freedom that relating to the right to work is doubtless one of the most idealistic. It is idealistic both in the sense that the demand is ethically undeniable and in the other sense that its practical realisation is immensely difficult, if not wholly impossible. So long, however, as the state fails to find a solution it behoves all private

employers to remove at least the most glaring defects of the existing conditions. One of the worst features of the system to which the age of inventions and industrial activities has given rise is the spirit of indifference with which employers engage and dismiss workers. It is nothing unusual to entice them by tempting offers away from modest but permanent occupations and after a short time, when a temporary boom has ceased, to shut the door on them. Not only is this an evil which directly engenders an alarming mass of workless people, who go to swell the ranks of the proletariat, but also in many cases the procedure is responsible for much overproduction. The charter of the Carl Zeiss Foundation embodies most significant provisions which take full cognisance of this evil and which are calculated to place an effective obstacle in the way of engaging additional workmen where there is little or no prospect of permanent work. By these provisions any person who has been employed by the establishment for at least three years (without a contract covering a certain long period), if dismissed from no fault of his, becomes entitled to a compensation in cash amounting after a three years service to at least half a year's wage or salary; and after five years service, which entitles to a prospective pension, the discharged employee receives by way of compensation at least an amount equal to the pension which would be due to him in respect of one fourth of the expired time of pensionable service.

Before the expiration of three years service compensation for discharge is paid on condition that the claimant has been at least six months in the employment of the establishment and that he is not being dismissed for any reasons attributable to his inefficiency or other personal reasons, but that his dismissal is solely occasioned by the exigencies of the factory, technical changes, and so forth. In this case the compensation consists in the payment of wages in respect of the sixth part of his expired time of service.

Obviously this compensation for discharge may be regarded as a species of unemployment insurance, or, if we prefer to give it another aspect, a kind of temporary provision for discharged persons, whereby they are enabled to seek without undue haste a suitable position, whilst indigence and anxiety would compel them to take the first best or worst thing that came their way.

In the course of time this provision has proved to be a great blessing. The financial responsibility which it imposes sternly discourages the unconsidered engagement of labour and, similarly, it does not favour arbitrary dismissals. On the other hand, it provides a dismissed person during a reasonably long interval with the requisite means of subsistence. The institution has proved particularly beneficent towards the end of the war

when it became necessary to reduce the excessively large body of workpeople who had been installed during the war. The inevitable discharges involved an expenditure of over £ 100,000 by way of compensations, and a great many have thereby been enabled to return to their old vocations or to seek fresh employment. The amounts paid by way of compensation are subject to the same rates of increases to meet the higher cost of living as the amounts paid by way of pensions. Recently a further expenditure of over half a million gold marks (about £ 50,000) had to be incurred to bring down the number of the factory workers from 5,500 to 4,400, which became necessary at the end of the period of inflation.

e) Finally, there are a large number of special institutions which benefit the employees of various grades in one form or another and some of which are without a parallel in other establishments. It may suffice to briefly review the following:

Payment of the standard rate of wages on all official holidays which happen to fall on week days (i. e. two or three days at Christmas, two at Easter, and two at Whitsun, on Good Friday, Ascension, the anniversary of the establishment of the republic on the ninth of November, New Year's Day, and the free afternoon of the Saturday preceding Whit Sunday). These official holidays amount to no less than 11 to 12 waged days or an addition of about 4 per cent to the annual wage bill.

Payment of Wages in respect of time necessarily lost in the service of the home fire brigade. The standard time rate of wage is paid by the firm (in accordance with a paragraph of law) for the first day of unavoidable absence through illness, for absence occasioned by certain family events (such as confinements) or domestic occurrences (such as removals), the death of near relatives, etc., all up to the limit of one day.

In the event of the death of an office employee or factory worker payment of the salary or wages is continued for a period of a quarter of a year irrespectively of the length of service.

The *Ernst Abbe Fund* is administered by the executive committee of the Funds and provides relief in special cases of adversity which do not come within the scope of the sick funds.

Technical Scholarships. During each half year 100 gold marks are granted to five conspicuously gifted young Zeissians or to sons of persons employed in the offices or works to enable them to attend courses conducted at secondary technical schools and in exceptional cases even at polytechnical university colleges.

The *Works Savings Bank.*

Wedding and Jubilee Presentations, the latter being graded according to the nature of the jubilee.

Annual contributions to the *Continuation Schools* and the care of youth. For the latter purpose a comfortable home with large garden at the foot of the Landgrafen Hill has been placed at the disposal of the *"Ernst Abbe Youth"* scheme.

Workshops for practical instruction.

Medical Examination of apprentices (since the autumn of 1892 these are held twice a year), the object being to take prompt measures against affections and tendencies to which early adolescence is particularly liable. This institution, which in its way is probably quite unique, has proved a great blessing and several instances are on record where it has saved the lives of young people, as testified by convincing medical evidence.

Other institutions and bestowals will be referred to later on, since they are not confined to the immediate interests of the persons employed by the establishments.

The Question of Patented Inventions.

There is one particularly significant point which should not be passed over in silence if we would arrive at a full appreciation of the unparalleled evolution of the Jena Works along the path of practical optics. It is very widely held that a new enterprise and its early development needs above all an extensive and effective protection of its products. Prominent among these protective weapons are protective tariffs and letters patent for the protection of inventions. The Zeiss Works furnishes an interesting example of the successful rise of a new undertaking to a foremost position in the world without any such aids. The protective tariff which has been placed on optical products and scientific instruments has never been very considerable, whilst it was not until 1890 that the Jena establishment began to take out patents. Over four decades it had proceeded on its upward trend without any patent protection whatever, and yet its microscopes have obtained the ascendency over all others, and that solely by the sheer force of quality. It was Abbe's wish that likewise in future no new devices which serve the purposes of study and scientific research should be made objects of protection by letters patent.

Actually this attitude of commercial renunciation is continually shrinking in its practical significance, for in these days there are few instruments

invented for scientific investigations which are not promptly applied to industrial or military uses.

One after another new branches had grown out of the healthy stem which had its root in the soil of the original microscope workshop, and the majority of these branches were new in a two-fold sense. Not only did they involve activities on new ground, but also they furnished products which were of a new character, optical instruments, in fact, endowed with qualities which had not existed before. The very first photographic lenses and telescopic instruments sounded a new key. It then became a vital necessity to protect the first fruits of the strenuous efforts which had produced them against the ravages of predatory competition. Hence every time a notable success was achieved on a new ground the invention must needs be fortified by patents.

Now the erection of such protective fences is a wholly unproductive task. Persons engaged in it are performing garrison work only. Not solely though, for in a measure their work is educational. We have not failed to realise that such a thoroughly organised system as has been developed in Germany and the United States, as distinguished from France, say, does carry instruction to the country's technical profession, inasmuch as it renders the mental side of technical production less fragmentary and hence imparts to it a greater continuity of thought. Within the compass of an individual undertaking a like influence arises from that form of occupation which is directed upon the widest attainable protection of the inventive idea. It may indeed happen as the result of such a procedure that an analytical study of the essence of the invention may point to new roads in the direction of synthetical creation.

Bestowals upon the University.

Under the economic conditions of our modern industrial system it has become more and more difficult in all phases of active life for the small man to hold his own in the race against the great. This applies not only to industry and commerce. We see the same forces in operation in the relation of states and in all the branches of their functions. A small state which desires to share in the blessings of the higher education afforded by the university is in an anomalous position, since there is no such thing as, say, half a university, whereas in proportion to its size and resources this may be the justifiable limit of its resources and needs. The Saxon dukedoms, which have arisen out of the old electoral principality

of Saxony, had only a full million of inhabitants, whereas the Prussian Rhine Province had a population of nearly seven millions. In these circumstances it is obvious that even the most stupendous efforts would not have rendered it possible for the small Thuringian States to endow the University of Jena to anything like the extent that the Prussian State was able to do in the case of the University of Bonn. And even the formation of the aggregate Thuringian State has not made any appreciable difference, since the whole state has only one and a half million inhabitants and cannot boast of national wealth. In these circumstances it is very doubtful whether the Thuringian University would ever have been able to satisfy the ever rising educational demands of our days unless in the shape of rich endowments private aid had come to the rescue. Amongst these the endowment provided by the Carl Zeiss Foundation is by far the most important, in fact, we need not hesitate to assert that until the foundation of the University of Frankfort no sums like those with which we are here concerned had ever been bestowed from private resources upon any university or scientific institute of any kind in Germany.

The sums provided by the Carl Zeiss Foundation for the benefit of the University of Jena are of a two-fold nature. In the first place there are regular grants subject in amount to a clearly defined scale and received by a special fund called the University Fund of the Carl Zeiss Foundation. Secondly, there are special grants. The former serve for the maintainance and expansion of institutes, their equipment and collections as well as for providing the salaries of a number of professors, while the special grants are devoted to certain specified purposes of some magnitude. Initially these grants were subject to the condition that they should primarily promote the study of the natural sciences, and more especially those efforts which stood in more or less close relation to the problems embodied in the industrial operations of the Carl Zeiss establishments, that is, mathematics, physics, astronomy, petrology, and chemistry. More recently (since the issue of the supplementary articles of the Foundation) the benefits to be derived from the grants have been extended to the general needs of the University. A notable asset of the University of Jena, which it owes to this same source, consists in two technological institutes, one for the study of physical, the other of chemical technology. These institutes have been founded with the assistance of Dr. Otto Schott's private resources and, excepting for the University of Goettingen, have no rivals among the universities of Germany. By these institutes the students, i. e. the future teachers, obtain valuable opportunities of becoming practically acquainted with the principal processes of physical and chemical technology, which

is a matter of the greatest importance in its relation to general education. As a matter of fact, these institutions are likewise of inestimable advantage to those who in the course of their studies decide for one reason or another to exchange a practical career for that of a teacher.

Mention may also be made of the new order of the professors' salaries, which surely could not have come into being without the cooperation of the Carl Zeiss Foundation and to which we shall have occasion to revert presently in another connection. A special magnificent contribution on the part of the Carl Zeiss Foundation has enabled the University to replace the old and wholly inadequate college buildings by an edifice designed by Theodore Fischer. This building, which was solemnly opened in 1908 on the occasion of the 350th anniversary of the University's existence, is is one of the finest structures of its kind in the whole German empire.

The People's Palace.

When we attempt to define the spirit which looms behind the provisions affecting the application of the surplus funds of the Carl Zeiss Foundation, in so far as they do not go to the direct benefit of the working staff of the undertaking, we cannot fail to experience a sense of embarrassment. It is not easy to find the right expression. It might be described as "democratic", Unfortunately, the word "democratic" conveys a variety of specialised political as well as loose colloquial meanings, and hence it only applies in our case if we take it in its widest sense as implying the inclusion of the entire population of a country in a social and political unit. It implies that no social section should enjoy privileges over another. In a democracy it may often seem as if this principle were not upheld, as if indeed the lower strata of the population with their working classes were the truly privileged classes. The simple explanation of this seeming anomaly is that in the past this class has met with such a conspicuous measure of repression and denial that it has for more evils to make good than the favoured strata.

Apart from the immediate aims of the works establishments and the financial support of the university the charter of the Foundation stipulates in express terms that the resources of the Foundation shall be applied not only for the benefit of individual groups but that it shall also enhance the welfare of all coming within its scope. In particular, it sets it down as an inviolable principle that these resources shall be applied without regard to political party views, social differences, creed, or matters of domestic life. This principle has been rigorously maintained in all undertakings of

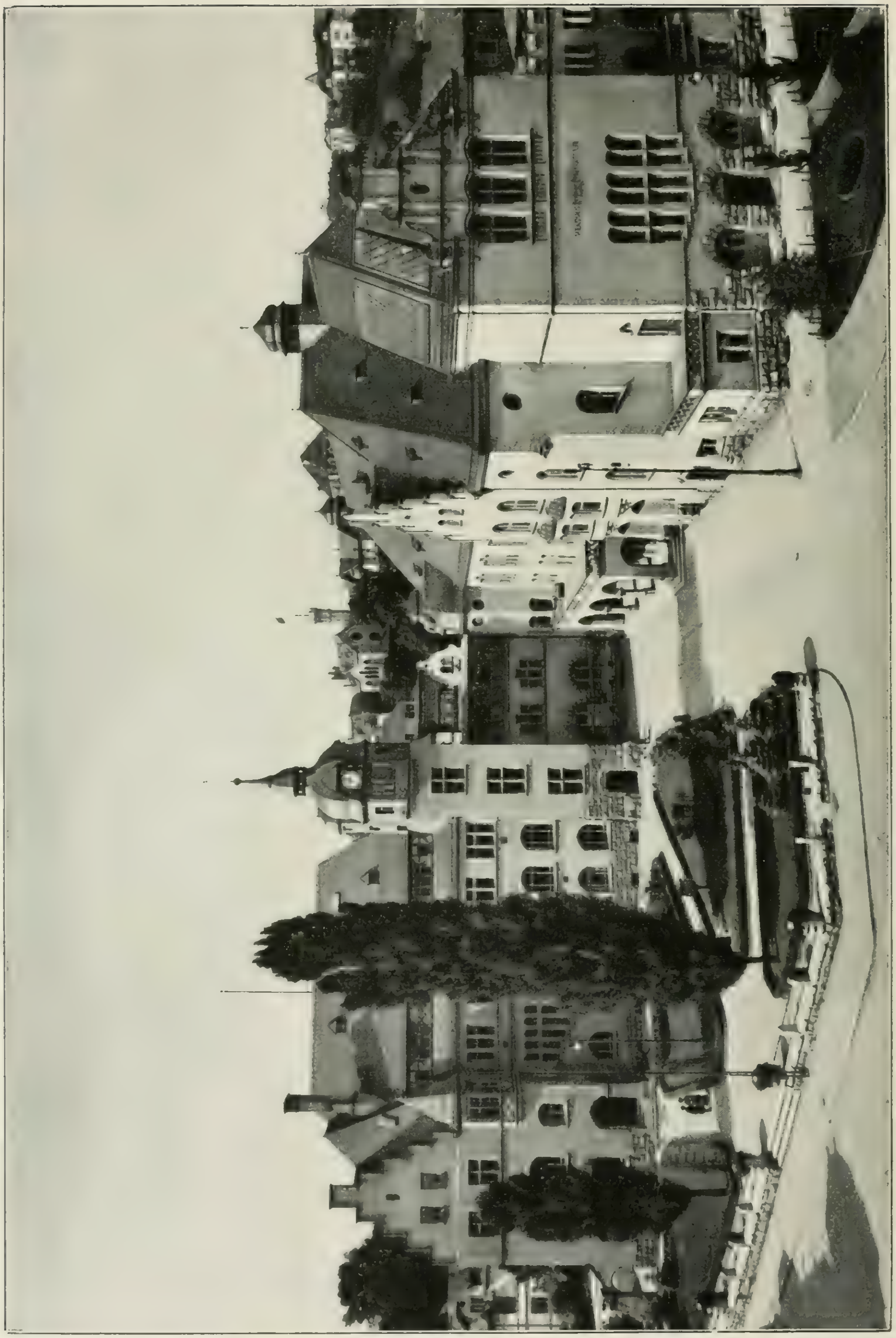

Fig. 247. The People's Palace.

the Foundation, but more especially in regard to the institution which may justly be described as the pride of Jena,—its *People's Palace*, or *Volkshaus*, as it is called in the vernacular.

Stepping out of the main office building of the optical works into the Carl Zeiss Platz, the visitor beholds an imposing building, which in its outlines and decorations has been moulded with fine discretion upon the style of the German renaissance. This building is the People's Palace, which was erected by the Carl Zeiss Foundation in the course of the years 1901 to 1903. This building comprises, amongst other rooms, a public reading room with its library, the literary museum, the Schaeffer Museum, a practical trade and handicraft school, a large assembly and concert hall, two lecture halls, an art gallery, studios for artists and amateur photographers, music rooms, etc. In 1903 the house was festively opened, naturally in the absence of Abbe, who had excused himself on the grounds of indisposition, aggravated, no doubt, by his unconquerable antipathy to being lionised.

A reading room association had already been founded a number of years previously and carried on in tenented rooms. This institution has now found its own home under the roof of the People's Palace. Its current expenditure is met in the greater part by contributions made by the Carl Zeiss Foundation and to a lesser extent also by the contributions of ordinary and honorary members. There are no other revenues since the free use of the reading room and library is open to all, and all contributions by such visitors who can afford them are entirely voluntary. Yet, although Jena, despite the population of 50,000 to which it has now risen, is still a small town, the Jena Reading Rooms may be fairly described as the most beautiful, the most modern, and the most comfortable in Germany, and thanks to the immense number of newspapers, journals, magazines, and pamphlets which are laid out it enjoys the relatively largest attendance in the realm.

In obedience to the fundamental attitude of the Foundation the political papers, of which there are roughly a hundred, appeal to all political creeds. In fact, the intention is that within these walls everyone shall be able to find what he seeks, and that it should afford a visitor who reads his own party paper at home an opportunity of expanding his vision and to develop his power of discrimination and his faculty of impartial reasoning by listening to voices from the other camps. Actually, the reading room knows neither rank nor social distinction; professors and students, men of means and working men are there to be seen peacefully seated side by side. The hall on the ground floor contains the political publications, while the corresponding hall on the ground floor is set apart for instructive and entertaining periodicals, of which there are considerably more than two

hundred. An adjoining room is replete with patent specifications, works of reference and a great variety of pamphlets dealing with the burning questions of the day.

The reading room is associated with a lending library which in the course of the year issues well nigh 150,000 volumes to the readers of Jena and the neighbourhood. The proportion of fiction and instruction is well balanced. A mere visitor cannot fail to observe that the industrial and agricultural workers constitute a notable proportion of the reading public. There are men and women who begin by having books recommended to them by the library attendants but ere long derive such educational advantages from their reading that they are able to formulate their own requirements.

Fig. 248. The Reading Room.

The same wing contains the manual training school and the Schaeffer Museum. The latter comprises a collection of simple but exceedingly varied instruments and appliances used in the elementary teaching of physics, which had been established by the private efforts of Prof. Schaeffer and which had been acquired by the Carl Zeiss Foundation at the instigation of Abbe. This concrete monument thus erected by Abbe to the memory of a worthy colleague provides an excellent equipment for the illustration

of the courses of lectures which are organised for the benefit of the young working people of the Zeiss Works. The museum joins on to a lecture theatre, which is specially fitted up for physical lectures and experiments.

The left wing, which we have just surveyed and the right wing are bridged by an intermediate building, which accommodates on its ground floor the last mentioned lecture theatre and on the floor above another lecture hall capable of accommodating 300 people. This hall is pictorially decorated by Erich Kuithan in a manner which at the first glance discloses the hand of the modern artist.

The whole of the right wing with the exception of a few rooms devoted to special purposes is occupied by a large hall capable of accommodating about 1,600 persons. This hall with its several annexes is the largest and also in an artistic sense the most distinguished hall of Jena. It is primarily designed for meetings of the factory and office staffs of the optical and glass works, which now musters some six thousand persons and therefore were formerly unable to hold fully representative meetings. Apart from this primary purpose this hall is available for meetings, lectures and other events organised by any of the many political, economic and other groups. Here again the primary mission which this hall is required to fulfil is that it should be at the service of all who need it, without regard to party or creed, and even bodies pursuing unpopular aims were not to find doors inhospitably closed against them by partiality and self-interest.

This hall is also very extensively used for science and art lectures and demonstrations, and for concerts. The latter owe their success in no small measure to an organ of over 2500 pipes embodying the most modern resources of the art of organ building. Finally it provides a splendid home for social gatherings of all circles which make up the population of Jena.

Other Public Benefactions.

If we have devoted some little space to the description of the People's Palace at Jena it is because it embodies a quite unique conception, at least so far as Germany is concerned. The space at our disposal will only allow us to briefly review some of the other activities of the Carl Zeiss Foundation for the benefit of the community.

The Jena Building Society. Already before the war the scarcity of small dwellings had become a serious matter. It was the natural consequence of the rapid development of the small town, in which alone the two establishments of Zeiss and Schott and to a less, but still considerable,

extent the railway works there established and a few other undertakings had occasioned a yearly increase of 6 to 8 per cent in the population. This deficiency has been met to some extent by the Building Society which has been established in 1896 at the instigation of Abbe. In the course of time it gradually furnished good and economic houses for some five hundred families, and at all times it has received the financial and personal support of the Foundation, the local state insurance institute, and a few persons of means, and more especially after the war the Carl Zeiss Foundation has assisted by making grants to meet the increased cost of production. Although in principle the society operates with its own resources, as derived from the contributions of its members, there is no doubt that neither its foundation nor its development would scarcely have been conceivable without the financial assistance to which we have referred.

The Cottage Association, whose object is to erect houses for single families, is likewise actively supported by the Carl Zeiss Foundation. During its thirteen years of existence it has succeeded in creating no less than 350 comportable homes in the open district situated between the Ziegenhain Valley and the Hausberg.

As an ally of the Building Society and the Cottage Association there is the *Settlement Department of the Jena Town Council,* which operates on the lines adopted by the city of Ulm and which has achieved excellent results. This scheme is likewise supported by the Carl Zeiss Foundation.

The Popular Instruction Classes and Social Evening Scheme, which was originated by the Comenius Society, are supported by substantial contributions furnished by the Carl Zeiss Foundation (in so far as the organisation is not entirely self-supporting). Since space does not allow us to go more fully into the work and influence of this notable institution, we must be content to mention that the lectures, concerts, dramatic and operatic performances there given have reached a very high level thanks to the untiring efforts of Georg Paga, their organiser. The extraordinary response with which this organisation has met on the part of all sections of the community bears eloquent testimony to the intellectual and artistic need which it supplies.

The *People's University at Jena,* which is very largely attended, is likewise linked by many ties to the Carl Zeiss Foundation.

The School of Opticians at Jena, whilst a self-supporting institution and entirely independent of all optical manufacturing concerns and absolutely neutral in its relations to these, has been liberally financed by the Carl Zeiss Foundation and naturally derives magnificent advantages from

the immediate nearness of a leading optical establishment. Its full and contracted courses are open to all practical opticians and are actually attended in an ever increasing measure by the proprietors and employees of optical businesses and other interested persons from all parts of the empire as well as from other countries. In course of time the attendance has increased to such an extent that the building has become wholly inadequate. In consequence, an imposing new building is in course of erection, which will be ready for the opening ceremony before long.

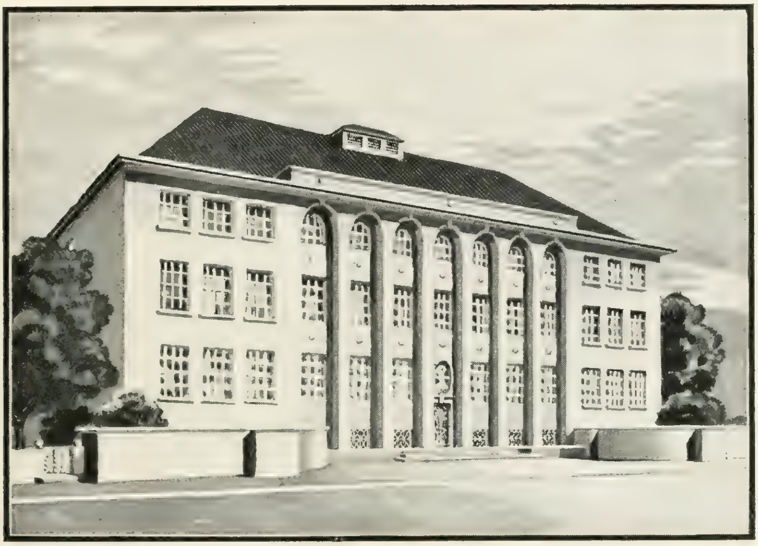

Fig. 249. State School of Practical Optics.

A new large building has likewise been erected for the accommodation of the Main Station for Seismological Research. This is an imperial institute but is largely supported from private resources, and here again the Carl Zeiss Foundation occupies a prominent position.

A special group, which likewise derives aid from the Carl Zeiss Foundation, comprises an institution for the wellbeing of children. These are the *Jena Children's Hospital* which has recently been extended by large annexes, the Children's Home with Infants' crêche at Jena, and the *Children's Reconvalescence Home at Bad Sulza.* All these institutions are dispensing manifold blessings to the local community under the care of Prof. Ibrahim, Mesdames Ebsen and Unrein.

In addition to all these gifts considerable contributions are made to Holiday Colonies for Children, a recovery home in the woods, for the work of the Women's Union, to sporting associations, and others.

The *Public Baths* at Jena were completed in 1909 and partly owe their existence to the munificence of the Carl Zeiss Foundation. It may unhesitatingly be described as one of the finest in the country. The building, which presents bold architectural outlines, is applied to the purpose which it serves in accordance with the latest achievements of modern hygiene.

Fig. 250. The Public Baths at Jena.

Private baths, shower baths, steam baths, and sun baths are provided at moderate charges. A large swimming bath enjoys great popularity. The employees of the Carl Zeiss establishments pay 40 per cent of the charge, the firm paying the balance of 60 per cent into the Public Baths account. Since the opening of these public institutions the use of the works baths within the Zeiss Works has been restricted to the needs of persons performing soiling work. The deficits encountered in the upkeep of the baths, especially after the war, have been borne in equal shares by the town council and the Carl Zeiss Foundation.

The principles of impersonal thinking and equity which dominates the aims and provisions of the Carl Zeiss Foundation, as we have had

occasion more than once to emphasize, take us back once more to the *relations which subsist between the Foundation and the University.* The particular aspect to which we are now led is the new order of the professorial salaries, whereby, with the unstinted aid of the Foundation, an end has been put to a situation which for years had been felt to be quite untenable. Formerly the Jena professors received their emoluments in two ways. In the first place, they received a very moderate salary which was far short of the customary amount; and, secondly, by way of partial compensation they were exempted from rates and taxes. It will be realised that this species of compensation was a very big item to an opulent person but of little or no consequence to one without substantial means, and it is equally

Fig. 251. Abbe Memorial.

apparent that the system not only placed the Jena professors ethically and socially in a far from enviable position but also gave those professors who happened to have private incomes an immense advantage over their poorer colleagues. It will be seen that this anomalous state of things operated as a direct challenge to the ideas of Abbe and the resources of the Carl

Zeiss Foundation. The challenge has been accepted, and as the result of combined efforts the exemption from taxation has been abolished and a new order of the professorial salaries has been established. Nothing would seem more reasonable than that Abbe, in laying this material burden upon the Foundation, should have coupled two conditions with the supply of the requisite funds. These conditions disclose, however, again a higher motive. They embody a further endeavour to uphold the principles of impersonal thinking and equity which is the very soul of the Foundation. These two conditions are, firstly, that no teaching should be accounted a heresy and that the mental and spiritual freedom of the teacher should not be assailed at the University on that score; and, secondly, that the institutions of the University, where this is practicable, should be available for the University extension, that is, for the wider *education and culture of the people.*

We have arrived at the end of our task. Within the limits of these pages we have sought to glimpse into the nature of a singularly constituted undertaking which bears the stamp of a closely tied bond between the ideal and the practical. We have glanced into the history of an enterprise which within a space of barely eighty years has achieved a first position in the world, and we have seen it completely transform by its influence and activities the once insignificant cradle of its childhood. The once small and silent university town has grown into an industrial town filled with the life of a pulsating populace.

It is a gladdening picture of widespread betterment, but there are always those who with knitted brow stand aside bemoaning the "desecrations" perpetrated by the unholy progress of man. They hear in their grumbling minds the reproaches of spirits of the past. Jena's greatest guest, they moan, he who again and again loved with fresh delight to dwell for a while in the "dear silly nest",—what would he have said of this "degradation" of it?—Well, we can only say, was it not he himself who led out his Faust from the lonely study into the wide world, there to find freedom and life in stirring the souls of others, nay, of all? The Jena of the past, that was the first part of Faust, the Faust of the bookman's study. Now, like the Faust of the second part, it has issued forth into the world of real life, there in its very centre to help in the building of the great dam

against the encroaching sea of misery and vice which threatens to submerge our vaunted civilisation. And the man to whom the Zeiss Works so largely owes its greatness, who created the Zeiss Foundation, and who ultimately broke down under the Atlas burden of his conceptions, his designs, and his deeds, piercing with his inspired vision the veil that as yet hid the future, may not he, like Faust, have experienced a prophetic wish mingled with a great hope:

> Such swarming multitudes I fain would see,
> Free people standing on a soil as free.

And this man, to honour whom numberless friends and grateful admirers of all stations congregated to erect to his memory a worthy monument conceived and produced by Van de Velde, Meunier and Klinger, has he not kindled a fresh hope in our hearts by throwing a shaft of light upon the piece of the track that leads out of the terrible modern labyrinth that we are accustomed to call "the social problem"? Surely, we are justified in hoping in a spirit of strong assurance that the foot-prints which he has left upon his upward path will

> Not with the ages fade in air!

Epilogue.

An interval of ten years lies between the appearance of the fourth and the present fifth edition of this book. That interval covers a vast slice of history. More has happened in these ten years than is commonly allotted to many decades, if not centuries. The course of the great war, which began as an apparent success for the German arms, has ended in a catastrophical defeat. Germany has had a peace of force laid upon her shoulders, the terms of which are full of crushing impracticabilities. The revolution by which the German people have sought the air of freedom has produced a complete social and economic inversion. Economic life has been shaken to its very foundations, and as yet no one may venture to predict when it will regain its stability. The German people are impoverished, their savings, large and small, are gone and their purchasing powers have dwindled to the lowest level. The new order, resting as it does upon the foundations of the constitution of the German Republic and the supplementary strength of its new code of laws, is passing through oscillating and not always successful experimental stages in its efforts to attain a practical form.

It goes without saying that such vast changes as Germany has experienced were and still are bound to affect such a vast organisation, both economic and social, as the Carl Zeiss Foundation with its working establishments. We very naturally ask, how has this entirely new and unique organisation fared in these abnormal times of the world's history and how have its fundamental principles and practical mechanism, as instituted by Abbe, stood the fierce test of the great war and its aftermath? Again and again this question has been put in the course of the last few years to the author of the preceding editions of this book, and it was not an easy matter, in some respects even impossible, to give a concise answer. Even now it would be obviously impossible to formulate a conclusive answer.

On the purely economic side we are concerned with influences which in varying degrees have affected all large manufacturing concerns without distinction. The Zeiss Works, one half of whose products were destined

for the use of the army and navy already before the outbreak of the war, became engaged almost exclusively on implements of war. The needs of the times created such an intense and extensive activity that the number of employed workers grew continually, despite the dearth of labour occasioned by the contingencies of the war. At one time the number of employees rose to more than ten thousand, one half of whom were women. At the end of the war the Zeiss Works had 8700 persons in its employ. At a stroke the demand which had created the need of such a staff came to an end, for the small supplies which were required for the equipment of the newly created Imperial Defence Army scarcely merited consideration in view of such a large number of employees. Moreover, the abnormal conditions relating to property and income, on the one hand, and the price standards, on the other, added immensely to the difficulties of obtaining a market within Germany, so that it was only by an intense and extensive cultivation of the foreign trade that the manufacture of the instruments required for peaceful pursuits could be maintained to anything like a tolerable extent. Moreover, serious barriers arose through the strengthened position of the foreign industry and the stabilisation of the curency. It became therefore imperative to proceed to the expedient of dismissing workers on an extensive scale and at the same time to keep a look out for such new objects of manufacture as might fit in with the existing order of things, without departing too far from the fundamental intentions of the founder, while at the same time offering a fair prospect of a material reward. Many attempts in this direction had to be relinquished, while others have been crowned with notable success, so that at the present time the establishment has been able to give full employment to at least 4500 persons. On the other hand, it has had to forego the magnificent surplus of earnings which had been such a notable feature before the war.

The question, however, which concerns us more immediately is how the Foundation as such has stood the buffeting storms of the war and the revolution which followed it. The answer is, it has survived these terrible perils. But even if it had not done so its surrender would not by any means have been a verdict proclaiming its fallacy. Failure in such abnormal times as the world has witnessed and is still witnessing does not prove that the underlying idea of an endeavour is wrong. Indeed, the worst that might logically be said about it would be that it is not adapted to meet the contingencies of abnormal times. It is fortunate that in this case we are not called upon to discuss this side of the alternative, for after full and searching consideration it may be said without hesitation that the Zeiss Foundation has stood the severe tests imposed upon it during these

abnormal times. Naturally, it is not pretended that the Carl Zeiss Foundation has stood like a charmed rock in the wild ocean untouched by its fury. Nothing of the kind! It has been shaken till it trembled, but it has stood firm and now stands firmer than ever. We have thus a positive proof that the foundations upon which Abbe has erected his edifice were thoroughly sound. It stood because Abbe's structure rested on a base which was commensurate with the breadth of his general outlook. Such events and vicissitudes as his foundation experienced (but happily have been spared the founder) could not possibly be foreseen by him, yet so free and broad was his outlook that he was able to adapt the provisions of his charter to the widest range of eventualities. Without this breadth of outlook the directors of the Zeiss Works would have found themselves faced by insuperable problems. What, however, is still more significant is that the fundamental paragraphs of the charter, which embody, as it were, its very soul, are not amenable to any modification whatsoever, so that if these fundamental provisions had come into irreconcilable conflict with the spirit of the times the dissolution of the Foundation would have been the inevitable consequence. It is precisely this provision which has imparted to the Foundation the character of a rock amidst the surging waves. And when the raging waves rise to their highest and threaten disaster to the workers on that rock, what more natural than that it might occur to them, perhaps only in the eleventh hour, to pour oil on the raging waves, unless they should happen to be too unreasonable to realise that if disaster were to happen they would be its very first victims!

If we proceed to examine in detail the effect of recent events upon the life of the Carl Zeiss Foundation, the first notable fact which strikes us is that, whereas the industrial undertakings operating on the old established conceptions, especially the majority of limited liability companies, were compelled to accept the consequences of the new conditions, the Zeiss establishments were able to maintain every existing link in its internal organisation as far as it was practicable to do so with its available means (and more than once beyond these). Everywhere except within the Zeiss Foundation the pension funds perished, while the sickness benefit societies were plunged into a desperate position. The Zeiss establishments were able to maintain these and other institutions, and on the whole they function sufficiently well to give general satisfaction. Even compensations in respect of dismissals have been duly paid, although the amounts involved amounted to hundreds of thousands of pounds, and it must not be overlooked that, naturally, with Zeiss as elsewhere the available means had melted away to an alarming extent by the devaluation of investments.

Even the various welfare institutions and the participation in their benefits have been maintained and new ones have come into existence, amongst these a children's hospital and an emergency kitchen, which is still maintained by regular contributions on the part of the Foundation establishments and the town council.

All this has become practicable only by a broad provision in Abbe's deed of donation, whereby the trustees are permitted to exercise the widest powers of initiative in taking up new branches of manufacture. Spectacles and magnifiers, headlights for automobiles and reflector lamps furnishing a rational mode of illumination are all such indispensable articles that even in times of bad business they remain fairly remunerative, though unfortunately, as soon as they are placed upon the market by the Zeiss Works they are promptly imitated. This, however, is a fate which, after decades of experience, the establishment has learned to accept with cheerfulness. There is, however, one thing which cannot be imitated by firms which primarily work for the owners' profit, which is a readiness to improve in every sense the working system in the interest of the workers so as to maintain a working *élite* and to raise the economic success of the whole. As an incidental result of these efforts gigantic new buildings have come into existence for which at the moment there may be no adequate use but which stand in readiness to meet an extended scope of manufacture in the event of an improvement in the existing conditions justifying or necessitating expansion.

From all this it follows that no exaggerated optimism is required to look forward with confidence to a time when such a scheme as that initiated by Abbe and as practically embodied in the Carl Zeiss Foundation with its industrial undertakings will rise with renewed vigour out of and above the ills and storms of the second and third decades of our century and that it may continue to serve as a beacon of industrial culture to the honour of Ernst Abbe.

APPENDIX

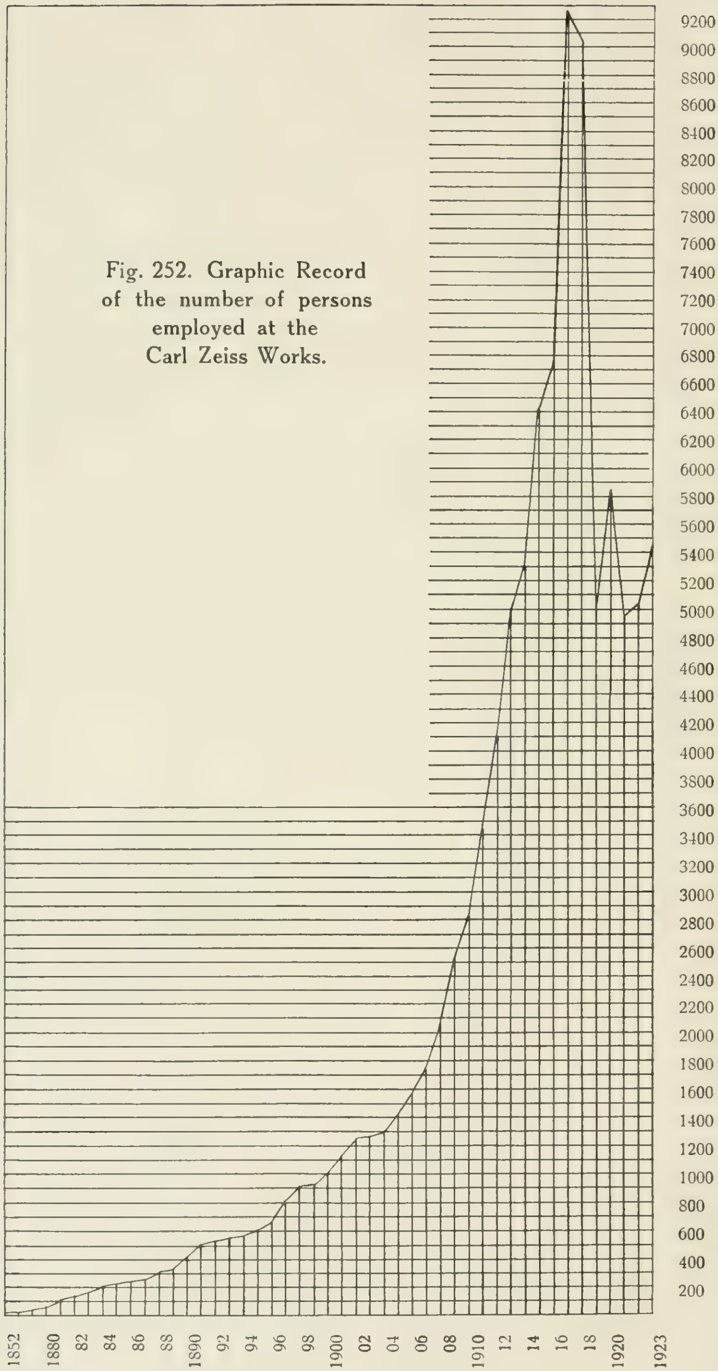

Fig. 252. Graphic Record of the number of persons employed at the Carl Zeiss Works.

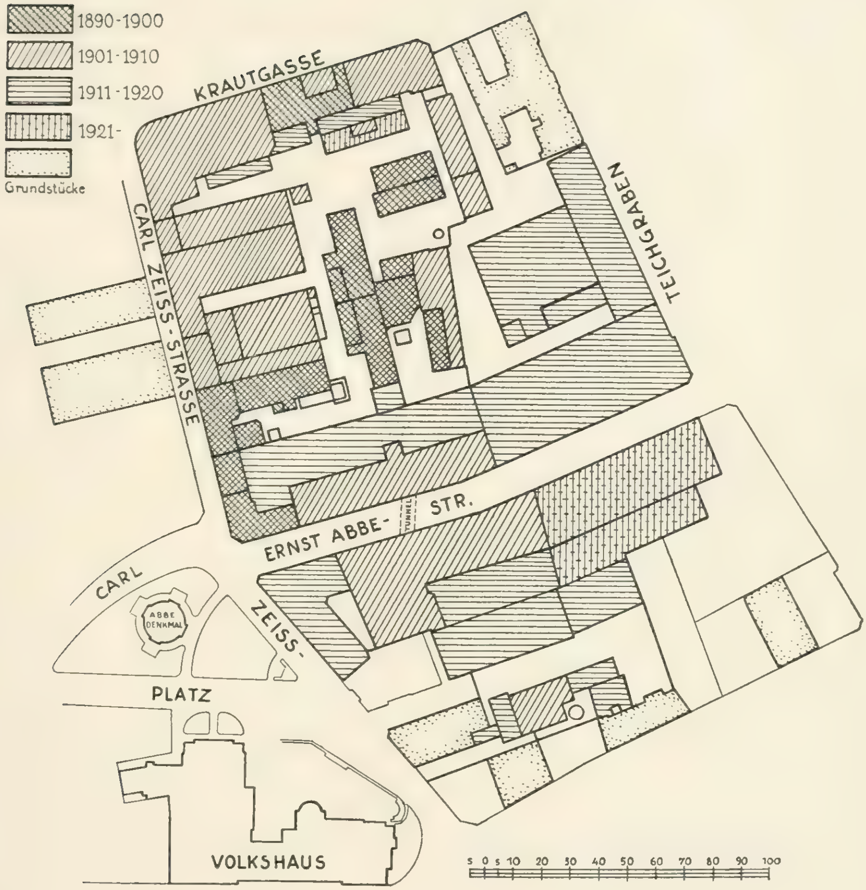

Fig. 253. Growth of the Factory Buildings.

Note: Different shadings within one and the same contours relate in most cases to reconstructions or extensions, etc.

Chronological Synopsis of the most important Inventions and New Instruments constructed at the Zeiss Works.

(The dates apply to those of the first published notices.)

1868 Introduction by Abbe in the Zeiss Works of the procedure by which every optical element which enters into the construction of the microscope is completely predetermined in accordance with theory.
1872 Abbe illuminating apparatus with a numerical aperture exceeding 1.0.
„ Issue of the first microscope immersion objective computed by Abbe's system.
1874 Abbe refractometer and spectrometer.
1878 Homogeneous immersion lenses.
„ Blood corpuscle counting apparatus.
1881 Abbe drawing apparatus.
1884 The Abbe dilatometer.
1885 Photo-micrographic apparatus.
1886 Apochromatic objectives, compensating eyepieces, and projection eyepieces.
1888 Large projection and photo-micrographic apparatus.
1889 Monobromnaphthalin immersion objective of num. aperture 1.60.
1890 The "Anastigmat" (photographic objective), later on named "Protar" lens.
1892 Crystal refractometer.
1893 Binocular field glass and stereoscopic telescope with image erecting prisms.
„ Stereoscopic range-finder with immovable scale and wandering reference mark.
„ First (Abbe) internal correction for range-finders.
„ Butter and milk refractometers.
„ Abbe comparator.
1894 Sighting telescopes for guns.
1895 Double "Protar" (photographic objective).
1896 The "Planar" objective.
1897 Binocular microscopes with image erecting prisms.
1898 Microscope body with new micrometer motion.
„ The "Epidiascope" (Projection apparatus, for illumination by incident or transmitted light).
1899 Dipping refractometer.
„ Transverse telescope.
„ Martens metallographic apparatus.
„ Binocular corneal microscope.
1900 Prism sighting telescopes for guns and rifles.
1901 Stereo-comparator (for astronomical, topographic and meteorological purposes).
„ Signalling apparatus for artificial light.
„ Heliographs.
„ Signalling equipment.
1902 The F/6.3 "Tessar" (rapid universal photographic objective).
„ Copying Tessar.
„ Ultra Microscope.
„ The Verant.
1903 Viewing Telescope.
1904 Periscopes for submarines.

1904 Photographic yellow-glass filters.
„ Verant magnifiers.
„ Illuminating apparatus for operating tables.
„ Improved paraboloid condenser for dark-field illumination.
„ Stereo-photogrammetric coast surveys from a ship.
1905 Rapid "Magnar" telephoto objective.
„ Anastigmatic magnifiers.
„ Binocular viewing telescopes.
„ New solar prisms.
„ Astro U.-V. Triplet (astro-photographic objective).
„ Monocular range-finder, in particular with invert image.
„ Mast telescope.
„ Depression range-finder (for a high station point).
„ Triple mirror.
„ Spheroidal mirror for searchlights.
1906 Flicker microscope.
„ Adjusting device for guns.
„ Compass director.
„ New telescope mounts.
1907 Hyposcope.
„ Variation of the magnification by change of objectives.
„ Multiple wandering reference marks in stereoscopic range-finders.
„ Pancratic sighting telescopes.
„ Special forms of apparatus for colour photography by interference.
„ Spectrum apparatus with stationary arm.
„ F/3.5 "Tessar" lens for portrait photography and cinematograph work.
„ F/4.5 "Tessar", being a rapid universal photographic objective.
1908 Projection screen with a metallic surface.
„ Monocular range-finder with fixed scale in the field of view.
„ Director with corrector for range-finders.
„ Additional tube and adjusting device for guns.
„ "Dukar" filter for autochrome photographs.
„ Point-focal spectacle lenses ("Punktal lenses").
„ Aplanatic condenser for micro-projection.
1909 Gullstrand cataract lenses ("Katral lenses").
„ Illuminating apparatus for dental and industrial purposes.
„ Cystoscope combinations.
„ Binocular magnifiers.
„ Zeiss-Orels stereo autograph.
„ New form of the four-lens Protar lens.
„ Biaxial telescope for surveying levels with reversible bubbles.
„ Levelling telescope with insensitive focusing.
„ Prism combination for viewing without parallax the bubble without graduation.
1910 Invert range-finder with variable point of coincidence for making a transition from ground to aerial targets.
„ Stadiometric theodolite.
„ Telescopic spectacles.
„ Haber-Löwe industrial interferometers for gases and liquids.

1910 Aplanatic lamp condensers for photo-micrography and projection with Nernst lamps and with arc lamps taking a small current.
„ Sighting apparatus for discharging projectiles from aeroplanes and airships.
„ Cardioid ultra-microscope.
„ New binocular eyepiece for astronomical purposes.
„ The "Double Amatar" F/6.5, being a rapid symmetrical objective for all-round work.
„ The "Orthoprotar" F/8, being a symmetrical objective for photographic purposes.
„ Folding range-finders.
„ Telescopic spectacles.
1911 Extension of the applicability of the stereo-photogrammetric method to horizontal axes directed at any angle.
„ Precision level with optical displacement parallel to the sighting line.
„ Ophthalmoscope.
„ Tele-spectroscope.
„ Small projection apparatus for lantern slides with hand feed arc lamp.
„ Motorcar projection headlights.
„ U.-V. filters and U.-V. filter lamp for the luminescence method of analysis.
„ Sighting telescopes with revolving eyepieces for balloon ordnance.
„ Telescopic magnifiers.
„ Laryngeal mirrors.
„ Balloon cameras, $f = 30$ cm. and $f = 70$ cm.
„ "Triplet" F/5, $f = 50$ cm. and Triplet F/5, $f = 70$ cm., being rapid long-focus objectives, mainly intended for aerial photography.
„ Stereoautograph.
1912 Reading devices for theodolites.
„ Metallographic arrangement of the Le Chatelier type.
„ Three-lens "Triotar" photographic objective.
„ Slit lamp for the examination of the eye.
„ Prism apparatus for determining the angle of squint.
„ Anisometropia spectacles.
„ "Umbral" sight protecting glasses.
„ Bifocal "Infral" and "Supral" spectacle lenses.
„ Triple operating lamps.
„ 12×9-cm. aeroplane camera, $f = 25$ cm., F/3.5 with mushroom and pistol handle (Pistol camera).
„ Range-finder in which the eye is applied at a stationary height at all elevations.
1913 Photo Kaleidograph.
„ Homogeneous $^1/_7$ objective as introduced by Hansen.
„ New epidiascope.
„ Spectacle magnifiers.
1914 New movable revolving mark in the stereocomparator.
„ Extension of the application of the method of stereophotogrammetry to axes directed at all angles.
„ Front "Distar Lenses" for attachment to photographic objectives.
„ Photographic coast survey cameras, 40×12-cm., $f = 64$ cm.
„ Tele-photographic objective F/50, $f = 3$ m.
„ Triplet F/7, $f = 120$ cm., especially for aerial photography.

1914 Triplet F/50, f = 4 m., for tele-photographic surveys.
" Gun directing periscope.
" Searchlight Reflector without false images due to reflection.
" Stützer double-base range-finder.
1915 Large simplified ophthalmoscope and slit lamp. Vertex refractionometer for spectacle lenses.
" Tele-photographic camera F/50, f = 3 m.
" "Proxar lens", being a front lens attachment for taking near objects.
" Shear-jointed telescopic camera, for photographing through stationary shear-jointed telescopes.
" Dip and tilt indicators for aerial cameras.
" Anti aircraft order apparatus.
1916 Differential pupilloscope.
" Slit lamp in conjunction with the corneal microscope.
" Adhesion eye-lenses for conical cornea.
" Retinal photometer.
" Illuminating appliances with gas-filled film lamps.
" Field-glass stereoscopes.
" U-camera for photographing through submarine periscopes.
" Electrical blink light apparatus.
" Hand goniometer.
" Stadiometric theodolite.
1917 Laminar flap shutter for large photographic objectives.
" 30×24-cm. mapping camera, F/5, f = 50 cm.
" Camera for observing firing results.
" Roll film dark slide for large pictures, with suction device.
" Trench range-finder.
1918 Eye microscope (ultra and polarising microscope).
" Radiation mirror for the treatment of tuberculosis.
" 18×13-cm. Panoramic trench camera, f = 60 cm.
" Tele-photographic objective, F/50, f = 4 m.
" 30×24-cm. Balloon camera, f = 120 cm. with laminar flap shutter.
" Range-finder adapted for measuring vertical distances.
" Blink apparatus for long wave-lengths.
1919 Eye radiation apparatus for the treatment of tuberculosis.
" Slit arc lamp and red-free lamps for the examination of the eyes.
" Wide-angle field glass embracing an angle of 70°.
" Aircraft camera for photogrammetrical surveys from the air.
" Micrometer screw gauges, dial gauges and other precision gauge tools.
" Optical angle gauge.
" Screw profile gauges with knife edges.
1920 Reflector lamps for internal illumination.
" Ball reflector lamps (Operating lamps).
" Spectacle lens drilling machine and cutting machine.
" Introduction of the new mode of identification of microscope objectives in terms of their magnifications.
" "Bitumi" binocular tube attachment for microscopes, as devised by Siedentopf.

1920 Double eyepiece for microscopes for joint observation by two persons using the same microscope.
„ Comparison eyepiece for microscopes for comparing two different objects under two microscopes.
„ Field equipment for terrestrial photogrammetry.
„ Thermo-couples, apparatus for measuring radiated energy.
„ Koesters Interference comparator.
„ R-yellow filter and R-colour filter for process photography.
„ New sighting telescope for sporting guns.
„ Optimeter.
„ Workshop measuring microscope.
1921 Trial spectacle frames.
„ New Meyer microscope slow motion.
„ Skin microscope as designed by Prof. Otfr. Müller.
„ Siedentopf change-over condenser.
„ Binocular eyepiece for terrestrial and astronomical observations.
„ Teletessar F/6.3, rapid tele-photographic objective.
„ Stereophotometer.
„ Stereoplanigraph.
1922 Eye radiation apparatus (ultra-violet).
„ Parallax refractionometer for testing eyes with respect to their visual acuity.
„ Tele-microscopes.
„ "Phoku": Photographic eyepiece as designed by Siedentopf for photo-micrographic work.
„ Micromanipulator as designed by Janse and Peterfi.
„ Sighting telescopes with variable magnifications ranging from 1 to 6×.
„ Loop galvanometer.
„ Outside and inside gauging machines.
„ Extension of the principle of the comparator.
„ Leading screw testing machine.
1923 Hand telescope with variable magnification ranging from 4 to 20×.
„ Theodolite embodying a new method of reading the circle.
„ Exposure scale indicator for photo-micrography.
„ Siedentopf capillary microscope.
„ New episcope and epidiascope.
„ Szegvari azimuth stop.
„ Arrangement for taking stereoscopic photographs of stationary objects with the aid of an ordinary photo-micrographic apparatus.
„ "Homals", being photo-micrographic and projection eyepieces for obtaining plane photographs of flat objects.
„ New metallographic microscope stand.
„ Stereoscopic projection.
„ $6 \times 4\frac{1}{2}$-cm. camera for use with the micro-spectroscope.
„ Works refractometer for mounting in the vacuum pan.
„ Mapping camera for photogrammetric surveys.
„ A Ducar filter for Agfa colour plates.
„ Method of gauging tooth-wheels by double images.
„ Outside and inside gauges with friction levers (Passometers and passimeters).

1924 Robon spectacles for protecting the eyes from heat rays and blinding light.
" Punktal near spectacles for presbyopia.
" Bell reflector lamps for inside and outside illumination.
" Step photometer.
" Hand camera for photographic surveys from the air.
" "Tessar" F/2.7 and "Triotars" F/3 and F/3.5, being objectives of great light-transmitting power.
" Apparatus for testing the profile of gear teeth.
" Projection Planetarium.

CARL ZEISS, JENA
General View of the Works
1926.

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